APR 14 1933

Volume XXXV April, 1933 Number 4

SOIL SCIENCE

Editor-in-Chief
JACOB G. LIPMAN

Associate Editor
HERMINIE BROEDEL KITCHEN

Contents

The Aspergillus niger Method of Measuring Available Potassium in Soil. A. Mehlich, E. Truog, and E. B. Fred 259

Photonitrification in Soil. N. R. Dhar, A. K. Bhattacharya, and N. N. Biswas 281

A Soil Temperature Installation. G. Allen Mail 285

The Dispersion of Soil-forming Aggregates. Cyrus L. Clark 291

The Effect of Soil Moisture on the Availability of Nitrate, Phosphate, and Potassium to the Tomato Plant. E. M. Emmert and F. K. Ball 295

The Forest Floor under Stands of Aspen and Paper Birch. F. J. Alway and Joseph Kittredge, Jr. 307

Soil Profile Studies: V. Mature Podzols. J. S. Joffe and C. W. Watson .. 313

Sixteenth Session of the International Geological Congress 333

PUBLISHED MONTHLY
THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES
Baltimore, Maryland, U. S. A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

ADVISORY STAFF

Prof. A. W. Blair, Dr. J. S. Joffe, Prof. L. L. Lee, Dr. H. C. McLean, Dr. S. Mattson, Prof. A. L. Prince, Dr. J. W. Shive, Dr. R. L. Starkey and Dr. S. A. Waksman, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

CONSULTING EDITORS

DR. F. J. ALWAY
University of Minnesota, St. Paul, Minn.

PROF. K. ASO
Imperial University, Tokyo, Japan

PROF. C. BARTHEL
Central Agricultural Experiment Station, Experimentalfaltet, Sweden

DR. P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa

DR. H. J. CONN
New York State Experiment Station, Geneva, N. Y.

PROF. DR. ALBERT DEMOLON
Ministry of Agriculture, Paris, France

DR. E. B. FRED
University of Wisconsin, Madison, Wis.

PROF. B. D. GEMMERLING
Agronomitcheskii Institute, Moskovskii Universitat, Moscow, U. S. S. R.

DR. J. E. GREAVES
Utah Agricultural College, Logan, Utah

DIRECTOR ACH. GREGOIRE
Agricultural Experiment Station, Gembloux, Belgium

DR. B. L. HARTWELL
26 Rowe St., Auburndale, Mass.

DR. D. J. HISSINK
Soil Science Institute, Groningen, Holland

PROF. DR. O. LEMMERMANN
Institut für Agrikulturchemie u. Baktericlogie der Landwirtschaftlichen Hochschule, Berlin-Dahlem, Germany

DR. C. B. LIPMAN
University of California, Berkeley, Calif.

DR. BURTON E. LIVINGSTON
Johns Hopkins University, Baltimore, Md.

DR. HENRIK LUNDEGÅRDH
Centralanstalten, Stockholm, Sweden

DR. T. L. LYON
Cornell University, Ithaca, N. Y.

DR. M. M. MCCOOL
Boyce-Thompson Institute, Yonkers, N. Y.

DR. W. H. MACINTIRE
University of Tennessee, Knoxville, Tenn.

DR. E. A. MITSCHERLICH
University of Königsberg, Prussia

PROF. C. A. MOOERS
University of Tennessee, Knoxville, Tenn.

DR. SVEN ODÉN
Central Agricultural Experiment Station, Experimentalfaltet, Sweden

PROF. D. H. PRIANISHNIKOV
Institute po Potshvoviedieniu Petrovsko-Razumovskaia Akademia, Moscow, U. S. S. R.

DR. THEO. REMY
Institut für Boden- und Pflanzenbaulehre, Bonn a. Rh.

PROF. G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy

DR. E. J. RUSSELL
Rothamsted Experimental Station, Harpenden, England

DR. O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.

DR. ALEXIUS A. J. DE'SIGMOND
Royal Hungarian Joseph University of Technical Sciences, Budapest, Hungary

DR. J. STOKLASA
Technical High School, Prague, Czechoslovakia

PROF. CHAS. E. THORNE
Ohio Experiment Station, Wooster, Ohio

PROF. N. M. TULAIKOV
Agricultural Experiment Station, Saratov, U. S. S. R.

DR. F. WEIS
Royal Agricultural and Veterinary College, Copenhagen, Denmark

DR. G. WIEGNER
Landwirtschaftliche Hochschule, Zürich, Switzerland

PROF. S. WINOGRADSKY
Pasteur Institute, Paris, France

Entered as second-class matter, May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879.

Copyright, 1933, The Williams & Wilkins Company

THE ASPERGILLUS NIGER METHOD OF MEASURING AVAILABLE POTASSIUM IN SOIL[1]

A. MEHLICH, E. TRUOG, AND E. B. FRED[2]

Wisconson Agricultural Experiment Station

Received for publication September 6, 1932

This investigation deals with the *Aspergillus niger* method of measuring the available potassium of soils. Recently this method has received considerable attention, and hence only a brief review of the literature relating to the method for measuring potassium and phosphorus will be given.

As early as 1909 Butkewitsch (2) suggested the use of *A. niger* as a biological indicator of the amount of available potassium and phosphorus in soils. A method in accordance with this was developed in 1909 by Koszeleskii (7) for available phosphorus, and the results obtained were found to agree closely with those obtained by extracting a podzol soil with citric acid and a chernozem soil with oxalic acid. The publications of Koszeleskii are in Russian, and hence are not easily accessible to investigators of other countries.

Apparently unaware of Koszeleskii's work, Pantanelli (18) reported in 1924 on the use of molds for testing the phosphorus needs of soils. He cultured *A. niger*, *A. oryzae*, and *A. flavus* on a sterilized mixture of soil and a nutrient solution containing 10 per cent sucrose and 2 per cent ammonium sulfate. The phosphorus which accumulated in the fungus mycelium was taken as a measure of the available soil phosphorus. He found that *A. niger* and *A. oryzae* gave the best results.

Benecke and Söding (1), in 1928, following the suggestion of Butkewitsch, used *A. niger*, and also other microörganisms, e.g., *Cladosporium herbarum* and *Stichococcus variabilis*. According to their method 50-cc. portions of the culture medium are placed in Erlenmeyer flasks and sterlized, and then to one series KCl is added in concentrations of 0.00025 to 0.002 per cent and in another series, soil sterilized at 150°C. for 15 minutes, is added in amounts from 0.12 to 5 gm. Both series are inoculated with a suspension of *A. niger* spores, and incubated at 35°C. After 6 days, the mycelium of the soil series is compared with that of the KCl series, and in this way conclusions are drawn regarding the available potassium content of the soil. The procedure for phosphorus is similar to that for potassium, except that 0.1 gm. KCl, and phosphorus in 0.002 to 0.0006 per cent concentrations are added to the medium. The authors considered their work to be of a preliminary nature and made no claim to quantitative results. Later, Simakova and Bovschik in 1932 (21) modified the method so as to make possible the obtaining of quantitative results for phosphorus. They avoided the occlusion of soil in the mycelium by bringing the medium to a boil, causing the soil to settle.

---

[1] This work was supported in part by a grant from the Wisconsin Alumni Research Foundation. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station.

[2] The authors are indebted to Prof. E. A. Mitscherlich of the University of Königsberg, Germany, for supplying the samples of soil and his results in table 9; to Mr. S. F. Thornton of Purdue University for supplying most of the soil samples and Neubauer values in table 8; and to Dr. N. J. Volk for the determinations of replaceable potash.

Lohmann (8) in 1931 reported on a method for determining the available potassium and phosphorus in soils which was essentially a modification of the Benecke and Söding method. He placed soil and nutrient solution in flasks, inoculated them with *A. niger*, and after 6 days of incubation placed the pad on a filter. The soluble salts were removed by washing, and the dried pad of soil plus mycelium was weighed. The weight of the soil was subtracted and from the weight of the mycelium the approximate amount of potassium absorbed from the soil was estimated.

Seidel (20) in 1931 recommended a new microbiological method in which yeast is employed as a biological agent to test for available phosphorus, and *Rhizopus arrhiza* to test for available phosphorus, potassium, and calcium. He claims to have obtained good results with *Rh. arrhiza* and urged its use in the determination of soil fertility.

Niklas, Poschenrieder, and Trischler (12, 13, 14, 15) used *A. niger* to determine the available potassium and phosphorus, and Niklas, Poschenrieder, and Frey (11) used the same organism to test for available magnesium. They and others at the Weihenstephan Station carried out experiments on various nutritive and other factors influencing the weight of mycelium of *A. niger* (24, 17, 4, 27, 26). As a result of extensive studies Niklas and Poschenrieder (10) recommended the following nutrient solution and procedure for carrying out the test:

Cane sugar	100 gm.
Citric acid	10 gm.
Ammonium sulfate	6 gm.
Peptone	1 gm.
P_2O_5(1.2152 gm. of $NH_4H_2PO_4$)	0.75 gm.
$MgSO_4$(0.6143 gm. of $MgSO_4 \cdot 7H_2O$)	0.30 gm.
Cu(0.0059 gm. of $CuSO_4 \cdot 5H_2O$)	0.0015 gm.
Zn(0.0044 gm. of $ZnSO_4 \cdot 7H_2O$)	0.0010 gm.
Fe(0.00498 gm. of $FeSO_4 \cdot 7H_2O$)	0.0010 gm.
Water, distilled	1,000 cc.

A 2.5-gm. portion of soil and 30 cc. of the nutrient solution are placed in a 75-cc. Erlenmeyer flask, inoculated with a suspension of spores of *A. niger* and incubated at 35°C. for 4 days. For more exact tests the mycelium is harvested after 6 days' growth instead of 4. The pads are washed and dried, first at 50° to 60°C. for 12 hours, then at 80° to 90°C. for 1 to 2 hours, and finally at 105°C. for 2 to 3 hours. If the weights of the dry pads fall below certain minimums, the need of potash fertilization is indicated. For calcareous soils, certain corrections are made. Their results with *A. niger* compared very favorably with those obtained with the Neubauer seedling method (16, 3).

Kiessling (5) also obtained good results with *A. niger* in determining the available potassium of soils. He found that the growth of mycelium is markedly stimulated by the presence of humic acid (6).

Recently Smith, Brown, and Schlots (22) reported the results of a comparative study of the Niklas *A. niger* and Truog chemical methods for available phosphorus. They found the two methods to check very well. They also concluded that the citric acid present in the medium is responsible for the solution of the soil phosphorus in the *A. niger* method, and the same results could probably be obtained with a simple citric acid extraction of the soil.

EXPERIMENTAL

Preliminary tests with the *Aspergillus niger* method of measuring the potassium deficiencies of soil, carried out according to the procedure of Niklas, excepting that 125-cc. flasks were used and drying of the pads was accomplished at 70° to 90°C. for 12 to 14 hours and then at 105°C. for 2 hours, gave results which in many cases failed to agree with those of a chemical method for re-

placeable potassium recently developed by Volk and Truog (28). Because of this lack of agreement, a number of experiments were made to determine, if possible, the disturbing factors which influence the weight of mycelium, and hence the accuracy of the method.

Comparison of different strains of Aspergilli

Since the weight of the pad is supposed to bear a direct relation to the available potassium of the soil, tests were made with a soil low in replaceable or readily available potassium, and to which were added increasing amounts of a soluble potassium salt. The results of these tests are given in table 1. The data show that at any one level of potassium the different strains of Aspergilli

TABLE 1

Comparison of the weights of mycelium produced by different cultures of Aspergilli

CULTURE	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES			
	K_2O added per 100 gm. of soil			
	10 mgm. K_2O	20 mgm. K_2O	30 mgm. K_2O	40 mgm. K_2O
	gm.	*gm.*	*gm.*	*gm.*
A. niger 1	0.96	2.29	3.51	3.81
A. niger 2	0.92	1.68	3.30	4.33
A. niger 3	1.31	2.20	3.10	3.90
A. niger 4	1.43	3.05	3.86	4.05
A. niger 5	1.08	2.56	3.50	4.45
A. niger 6	1.58	4.20	3.56	3.78
A. niger 7	1.70	3.60	3.90	3.55
A. fischeri 5041	1.63	2.36	2.89	3.64

produce different weights of mycelium. Strains 1, 2, and 5 seemed to be the most promising from the standpoint of weight in relation to available potassium. Strain 1 is an old stock culture of the department of bacteriology; strains 2, 3, 6, and 7 are recent isolations; and strain 5 comes from the Weihenstephan Station, Germany, and was obtained through the courtesy of Dr. Niklas and Dr. Poschenrieder. *A. fischeri* 5041 was a culture originally obtained from the U. S. Bureau of Chemistry and Soils, and now maintained in the stock collection at this station. The results of these tests clearly indicate the superiority of strain 5, and hence this culture was selected for use in all further experiments. Strain 4 formed only a fragile pad and thus was difficult to handle. Strain 2 closely resembled strain 5, and for this reason was used in tests of a number of soils, but it was found that the total weight of mycelium from four flasks seldom was more than 1.70 gm., whereas strain 5 proved more vigorous. Strains 6 and 7 produced maximum yields at the lower concentrations of potassium and hence were unsuitable.

Effect of age of spores on growth of fungus

To maintain physiological stability of stock cultures, the medium of Trischler (24), or a medium used here has been found satisfactory. The latter medium consists of 25 gm. malt extract, 20 gm. agar, and 1,000 cc. of water. Slant cultures on this medium are incubated at 30° to 35°C. until complete conidial formation takes place and then placed in an ice box. Stock cultures may be kept on this medium for at least 4 months without any loss in activity.

From these stock cultures inoculation is made to a medium low in phosphorus as proposed by Trischler (24) or to slants of the malt extract agar medium just described. After about 10 days' incubation at room temperature they are ready for use. The spores are washed out with two 5-cc. portions of water after they have been brushed loose with a wire loop. Of this suspension 0.5 cc. is used to inoculate each soil culture flask.

In order to determine the relation between age of spores and the weight of pad produced, a series of tests were made with spores from cultures kept at room temperature for 20, 40, and 60 days. The results of these tests showed that within the age limit of 20 to 60 days, *A. niger*, strain 5, produced approximately the same weight of pad. Somewhat similar findings have been reported by Frey and Poschenrieder (4), who carried on an extended study of this phase. They found that the highest weights of mycelium are obtained when spores from cultures 1 to 3.5 months old are used, and that older cultures give inconsistent yields, especially with media of low and very high potassium contents. It may be concluded that spore suspensions prepared from cultures not more than 60 days old will give the best results.

Factors influencing the weight of mycelium

Influence of reaction. In order to prevent the interference arising from the growth of various kinds of soil microörganisms, it is necessary either to sterilize the soil or else to provide a reaction which is sufficiently acid to prevent this growth and still allow *A. niger* to make a vigorous growth. Sterilization has not been found very satisfactory. The influence of the reaction on the weight of *A. niger* has been studied repeatedly in solution cultures under controlled conditions. In this investigation it was important to study the influence of reaction on the weight of mycelium when soil was present in the culture. The optimum reaction for conidia germination is pH 3.1 (9), and for growth it varies, the maximum weight of mycelium under sterile conditions being obtained when the acids produced are neutralized by the presence of an excess of $CaCO_3$. However, the increase in weight for *A. niger* due to the $CaCO_3$ is not as marked as for other species of *Aspergilli*. Niklas recommends 1.0 per cent citric acid in the medium giving pH 2.4 for the medium alone, and pH 2.4 to 2.8 in the presence of soils containing less than 1 per cent $CaCO_3$. In the presence of soils having more than 1 per cent of $CaCO_3$, the initial reaction is less acid and such soils should be neutralized with additional citric acid, thus maintaining a pH below the growth stage of most soil bacteria.

It may be well to describe a simple method for determining the carbonate content of soils, so that provision may be made for the addition of sufficient acid. Only soils which effervesce need to be neutralized. The method depends upon the evolution and volumetric measurement of the CO_2 evolved when the soil is treated with an acid. The apparatus consists of two 50-cc. Mohr burettes connected at the lower ends with about 2 feet of rubber tubing, and about one-half filled with CO_2-saturated water. The upper end of one burette is left open and to the upper end of the other is connected a 60 to 100-cc. wide-mouthed bottle. This bottle is provided with a one-hole rubber stopper carrying a glass tube having an elongated bulb at the lower end, of about 10 cc. capacity, which projects into the bottle. The glass bulb is provided with an opening about midway up on one side. The upper end of the tube is connected with the burette by means of rubber tubing.

The method of operation is as follows: One gram of soil is placed in the bottle (if carbonate content is very high, use 0.5 gm.) and 3 to 4 cc. of 5*N* HCl is placed in the bulb. The stopper is then tightly inserted in the bottle and the upper end of the tube connected to the burette. After the height of the liquid in the burette has been read, the bottle is tipped, causing the acid to flow out of the bulb onto the soil. The level of the liquid in the two burettes is kept about the same so as to avoid pressure and absorption of evolved CO_2, and when evolution of CO_2 is complete, the liquid in the two burettes is brought to exactly the same level and the burette is read again and the increase in volume of gas noted. The number of cubic centimeters of CO_2 evolved, times a factor, which, for a 1-gm. sample, is 0.405 at 25°C. and 745 mm. pressure, gives directly the percentage of $CaCO_3$ in the soil, and reference to the table by Niklas et al. (10, 14) shows directly how much acid is required to neutralize the carbonate present in the soil.

By reducing the citric acid content of the medium to 0.5 and 0.25 per cent, the weight of *A. niger* is not markedly influenced. With some soils, e.g., 39, 44 and 46 given in table 2, 0.25 per cent citric acid did not entirely suppress the natural microflora of the soil, and consequently low weights of mycelium were obtained. Tests indicated that when soil is not added and the citric acid is reduced to 0.5 per cent, the weight of mycelium produced will increase somewhat over that produced with 1 per cent of citric acid. Thus for germination and initial growth a reduced total acidity is beneficial. In the presence of soil, a portion of the acid is neutralized by the soil constituents, bringing about an optimum level. A reduction of citric acid to 0.5 per cent may be permissible with acid soils, but the improvement is negligible.

Sterilization and partial sterilization experiments were carried out which served mainly to indicate that equally reliable results can be obtained by the addition of citric acid with less labor and time. Mold spores can usually be killed in 5 minutes at 60°C. under moist conditions (29). Such heat treatments were made on several soils and no mold growth developed after 4 days' incubation. If, however, the initial reaction of the substrata is above pH 5.0, partial sterilization will stimulate bacteria, mainly the rod shaped spore-

formers, to such an extent as to limit or even make impossible the germination of the *A. niger* spores.

In the utilization of $(NH_4)_2SO_4$ by *A. niger*, sulfuric acid is liberated, and the greater the supply of potassium in the medium the greater the mold growth and the greater is this liberation. This results in a lowering of the pH which, however, is not serious as regards the results obtained. There is a voluminous literature in regard to nitrogen sources for *A. niger*, which, in the main, emphasizes the fact that the best sources are ammonium salts (19) and of these ammonium sulfate appears best.

TABLE 2

The influence of strength of citric acid in culture on the weights of mycelium of A. niger when grown on different soils

SOIL NUMBER	REPLACEABLE K_2O PER 100 GM. OF SOIL	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES		
		0.25 per cent citric acid in culture	0.5 per cent citric acid in culture	1.0 per cent citric acid in culture
	mgm.	*gm.*	*gm.*	*gm.*
1	0.7	0.79	0.94	0.92
4	3.5	0.91	0.98	0.98
8	5.5	1.10	1.06	1.02
15	7.2	1.29	1.16	1.22
17	7.6	1.21	1.16	1.00
20	8.3	1.40	1.46	1.37
34	11.2	1.25	1.28	1.33
37	12.6	1.46	1.30	1.34
39	13.1	1.07	1.38	1.54
44	14.2	1.13	1.63	1.40
45	14.7	1.81	1.93	1.88
46	15.0	1.65	2.07	2.24
51	16.7	1.25	1.80	1.77
53	19.2	1.58	1.66	2.00
58	20.9	1.77	1.94	1.80
60	22.6	1.56	1.77	1.78

Influence of various salts. Other factors influencing the weight of mycelium are time and temperature of incubation, amount of spore suspension used as inoculum, and concentration of nutrients. Most of these factors can be standardized and do not cause serious errors in the results. As a result of the great variations of soil type, however, changing nutritive influences are to be expected. Thus Vageler and Alten (25) found that Ca, Mg, and Na salts stimulate the growth of *A. niger* and give high potassium values for alkaline soils. Similar observations and studies were made by Vilsmeier (27) and Niklas, Vilsmeier, and Poschenrieder (17). Kiessling (6) also found that humic acid increases the weight of mycelium.

The influence of Ca, Mg, and Na carbonates on the growth of *A. niger* in soil culture was studied. Two soils which are on the borderline as regards the

need of potash fertilizer were selected and treated with increasing amounts of Ca, Mg, and Na carbonates in different combinations. The results showed that there is no increase in the weight of the mycelium but rather a decrease with increased additions of Ca, Mg, and Na carbonates. Tests with different Ca compounds and different amounts when added to soil cultures did not show an increase in the weight of the mycelium as compared to the non-treated cultures. From table 3 it is evident that the presence of $CaCO_3$ in soils does not materially increase the weight of mycelium, and the correlation with the Neubauer values is apparently not influenced by the $CaCO_3$ content. The results do not support the need of the correction for calcareous soils suggested by Niklas and Poschenrieder (10).

TABLE 3

The influence of the $CaCO_3$ content of soils on the weights of mycelium of A. niger as compared to Neubauer values on these soils

SOIL NUMBER	$CaCO_3$ CONTENT OF SOIL	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	K_2O PER 100 GM. SOIL		TOTAL SOLUBLE SALTS
			A. niger method	Neubauer method	
	per cent	*gm.*	*mgm.*	*mgm.*	*p.p.m.*
1649	36.4	0.87	8.6	0.6	1115
1800	0.0	0.84	8.0	1.2	165
1646	3.0	1.18	12.4	3.6	413
1798	0.0	1.09	11.3	4.8	82
1651	29.2	2.13	22.0	18.8	726
1581	0.0	2.10	21.8	18.2	702
1650	38.7	1.72	18.4	13.3	586
1648	0.0	1.77	18.8	13.3	616
1843	2.1	1.16	12.4	5.4	413
1738	0.0	1.46	15.6	5.4	173

It was found that the addition of $CaHPO_4 \cdot 2H_2O$ to the medium acts as a buffer and prevents the culture from becoming too acid. It favors the production of a mycelium with a firm structure. In the subsequent work, 0.072 per cent $CaHPO_4 \cdot 2H_2O$ was added to the nutrient solution.

Influence of acid radicals of potassium salts. Trischler (24) indicated that the addition of chemically equivalent amounts of different potassium salts gave different weights of mycelium, and concludes that *A. niger* cannot be used for accurate quantitative measurement of available potassium. This point was investigated, and the results are given in table 4. It can be seen that the differences in weight of mycelium are not very great, with the possible exception that when K_3PO_4 was used somewhat low results were obtained.

Influence of other soil constituents and stimulants. Steinberg (23) reported that many salts, including those of the heavy metals, stimulate the growth of *A. niger*. Since such constituents may be found in certain soils, it seemed desirable to study the effect of them. A fertile soil and soil extracts from it

were added to cultures containing the regular culture medium, but varying amounts of soluble potash. At the higher concentrations of potash, where nearly maximum growth took place, the addition of soil or soil extract caused a slight improvement in growth of *A. niger* and prevented the usual decrease in growth that ordinarily takes place with excessive concentrations of soluble potash. It may be concluded that any effect brought about by certain soils, because of their content of special constituents and stimulants, is insufficient to influence the results of the method for practical purposes.

TABLE 4

The effect of adding different forms of potassium salts on the weights of mycelium of A. niger

K_2O added	Forms of potassium salts added and total weights of mycelium from 4 cultures					
	KCl	K_2CO_3	K_2SO_4	KNO_3	K_3PO_4	KH_2PO_4
per cent	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0.001	1.64	1.83	1.61	1.75	1.48	1.69
0.002	2.39	2.51	2.04	2.27	2.05	2.17
0.003	2.85	2.95	2.64	2.66	2.41	2.54
0.004	3.68	3.88	3.07	3.23	2.66	3.07
0.005	4.35	4.42	3.88	3.94	3.58	3.89
0.006	4.70	4.84	4.31	4.48	4.16	4.01
0.007	4.64	4.76	4.58	4.75	4.40	4.67
0.008	4.60	4.55	4.74	4.77	4.72	4.93

Description of method finally adopted

A nutrient medium is made up according to the method of Niklas et al. (see p. 260), excepting that 0.72 gm. of $CaHPO_4 \cdot 2H_2O$ per liter is added, which acts as a buffer, furnishes calcium, and was found to help in the production of a firmer and better pad, especially with the very acid soils. If the medium is to be stored more than 2 days before use, it should be sterilized at about 115°C. for 5 minutes.

The soil sample is air dried, passed through a 20-mesh sieve, and 2.5-gm. portions in triplicate or quadruplicate are placed in 125-cc. Erlenmeyer flasks, which have been thoroughly washed but not sterilized. In the case of peats, the sample is wrapped in potash-free filter paper and then dropped into the flask. Otherwise it is difficult, later, to separate the mycelium from the peat, which tends to float. Nutrient medium, 30 cc. per flask, and then spore suspension, 0.5 cc. per flask, are added. The flasks are closed with cotton plugs, and the cultures incubated at 35°C. for 4½ days. The appearance of the cultures at this stage is shown in plate 1. An experienced operator can, by casual observation of the size and character of the pads at this stage, determine fairly well whether or not a soil is deficient in potash.

In order to obtain more definite results, the pads are taken out with a forceps, washed with running tap water to remove soil particles and nutrient

medium, pressed in the hand to dispel excess water, placed in evaporating dishes, and dried at 70° to 90°C. for 12 to 14 hours and then at 105°C. for 2 hours. The pads are then placed in a desiccator and later weighed. The total weight of four pads, or of three pads calculated to a four-pad basis, gives, by interpolation on curve II of figure 1, the milligrams of available K_2O per 100 gm. of soil.

If it is desired to analyze the pads for potash, they should be washed with distilled water in place of tap water, and after being dried and weighed in the usual way the pads are ground in a mortar. The pulverized tissue from two or three cultures is placed in a 50-cc. porcelain crucible and moistened thoroughly with a saturated alcoholic solution of magnesium nitrate. The alcohol is largely driven off with a low flame, and then the pads are finally ignited at a low temperature just high enough to give a slight redness to the bottom of the crucibles. It is very important that the temperature in the crucible does not exceed this; otherwise there may be loss of potash. The ash is crushed and then extracted with about 200 cc. of hot water on a filter paper, and the potash determined in the filtrate.

Application of method to the quantitative determination of available potassium

Not until recently has Niklas (10) suggested a method of evaluating the weights of *A. niger*, whereby the need of potash fertilization is indicated when the weights fall below certain limits. It seemed very desirable to develop a procedure which permits a quantitative determination. For this purpose the pads produced were analyzed for potassium and the results calculated on a basis of the amount of K_2O which would be absorbed from 100 gm. of soil, so that comparison might be made with other methods.

Analysis of the mycelium for potassium. Seventy-four soil samples were obtained from various sections of the United States, Hawaii, and East Prussia, Germany, and tested by the *A. niger* method for available potassium, and by a chemical method for replaceable potassium. The results of this work are given in table 6. It will be noted that *A. niger* absorbed more potash than is represented by the replaceable potash. This is probably because a mold, in growing for a period of 5 days, is able to utilize an appreciable amount of potash going into solution slowly from the feldspars and micas, whereas the method for replaceable potash, involving an extraction for a 5-minute period only, removes little other than replaceable potash. In all other respects the correlation between the two methods is quite uniform, and after once the results of the *A. niger* method are standardized with soils of known potash needs, the method can undoubtedly be used quite satisfactorily for determining the potash requirements of soils. In order to simplify the method for practical purposes, so as to eliminate the need of making potash determinations on the mycelium, it was decided to attempt to get the approximate amounts of potash absorbed by means of an interpolation method.

Interpolation on a curve. In order to determine the weights of the mycelium which would be produced with different amounts of soluble potash, *A. niger* was grown in regular cultures to which were added varying amounts of KNO_3 and soil extract with a little soil. The results of this experiment are given in table 5. Using the weights of soluble potash present in the medium as abscissae, and the weights of mycelium produced as ordinates, curve I in figure 1 was drawn. The data obtained with 74 soils, given in table 6, are also expressed in figure 1. Each cross represents the point of intersection between

TABLE 5

The weights of mycelium produced by soil cultures to which KNO_3 and soil extract were added

K_2O added as salt or soil extract on the basis of 100 gm. of soil	Total weights of mycelium after 5 days from 4 cultures	
	When soil extract was added	When KNO_3 was added
mgm.	*gm.*	*gm.*
2	0.78	0.82
4	0.99	1.03
6	1.15	1.21
8	1.34	1.36
10	1.62	1.58
12	1.83	1.77
14	1.94	1.98
16	2.13	2.13
18	2.33	2.35
20	2.44	2.46
22	2.63	2.65
24	2.80	2.76
28	3.07	3.13
32	3.39	3.37
36	3.50	3.62
40	3.82	3.90
50	4.20	4.38
60	4.59	4.61
70	4.80	4.76
80	4.79	4.81

the weight of mycelium and potash content of *A. niger* grown on a particular soil. Curve II, drawn midway between these crosses, shows that some of the latter fall a considerable distance from the curve, especially when high amounts of potash are present. This, however, is not a serious objection because the main object of a test of this kind is to distinguish the group of soils low in available potash from the group high in available potash. Since curve II represents data from actual soils, it was used, rather than curve I, in the subsequent work for estimating by interpolation the amount of potash absorbed and available.

TABLE 6

Weights, and potash contents of the mycelium of A. niger grown on 74 different soils, and the replaceable potash of the soils

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	PERCENTAGES OF K_2O IN MYCELIUM BY ANALYSIS	K_2O ABSORBED BY A. NIGER FROM 100 GM. SOIL	REPLACEABLE K_2O IN 100 GM. SOIL
	gm.	*per cent*	*mgm.*	*mgm.*
1	0.73	0.078	5.60	0.7
1649	0.98	0.071	6.90	7.2
2	0.66	0.109	7.20	1.1
3	0.83	0.096	8.00	2.0
4	0.70	0.114	8.00	3.5
8	0.98	0.082	8.00	5.5
10	0.83	0.096	8.00	5.8
6	0.74	0.143	8.40	4.7
7	0.92	0.091	8.40	5.1
9	0.91	0.092	8.40	5.5
14	0.90	0.093	8.40	7.0
19	0.94	0.097	9.10	7.8
31	1.16	0.080	9.30	9.9
5	0.98	0.097	9.50	4.6
17	0.82	0.125	10.20	7.6
16	1.00	0.105	10.50	7.3
21	1.04	0.103	10.70	8.3
15	1.24	0.087	10.80	7.2
1801	0.85	0.137	10.90	2.1
34	1.15	0.100	11.50	11.2
1646	1.18	0.102	12.01	8.9
28	1.33	0.105	14.10	9.4
37	1.43	0.102	14.60	12.6
1754	1.16	0.133	14.66	7.7
1634	1.80	0.088	15.18	8.8
46	1.83	0.086	15.70	15.0
77	2.03	0.083	16.60	10.9
50	1.59	0.105	16.70	15.7
1637	1.42	0.120	16.75	9.5
1632	1.57	0.108	16.75	8.7
1798	1.09	0.160	17.27	6.1
1845	1.49	0.116	17.27	9.8
1638	1.48	0.096	17.79	8.5
57	1.60	0.116	18.50	20.7
1845	1.49	0.127	18.84	9.8
1740	2.01	0.093	18.84	13.4
59	1.85	0.103	19.00	21.4
1648	1.77	0.108	19.10	14.3
73	1.89	0.102	19.36	13.15
1799	1.10	0.179	19.36	5.0
1581	2.10	0.101	21.04	18.5
1739	2.76	0.082	22.51	23.2
1740	2.01	0.120	23.55	13.4
1633	1.64	0.145	23.66	13.6
1577	1.92	0.128	24.35	14.4

TABLE 6—*Concluded*

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	PERCENTAGES OF K_2O IN MYCELIUM BY ANALYSIS	K_2O ABSORBED BY A. NIGER FROM 100 GM. SOIL	REPLACEABLE K_2O IN 100 GM. SOIL
	gm.	*per cent*	*mgm.*	*mgm.*
80	2.80	0.089	25.12	21.6
1643	1.69	0.161	27.20	10.9
79	3.50	0.092	32.36	38.2
1578	2.84	0.116	32.45	29.7
1844	3.05	0.110	33.50	17.0
72	4.28	0.079	34.02	26.0
67	4.42	0.082	36.11	27.8
62	3.50	0.104	36.30	41.9
1755	4.50	0.081	36.64	34.8
71	4.90	0.075	36.64	30.6
63	3.85	0.098	37.69	19.2
68	3.97	0.095	37.70	21.5
69	3.95	0.097	38.48	19.5
70	4.35	0.090	39.26	28.5
66	4.48	0.091	40.57	29.9
82	3.48	0.122	42.67	45.2
78	3.44	0.126	43.45	38.8
1848	4.61	0.100	46.32	37.9
75	4.55	0.104	47.11	29.5
74	4.90	0.097	48.16	29.3
1595	4.10	0.121	50.08	41.9
65	4.84	0.104	50.25	31.4
64	4.89	0.104	50.78	40.3
1846	3.84	0.133	50.78	29.4
81	4.60	0.112	51.86	46.1
1850	4.00	0.138	54.96	26.3
1590	4.54	0.130	59.69	59.1
1755	4.50	0.148	65.97	34.8
1582	3.97	0.087	68.30	108.2

Comparison of results with other methods

In tables 7, 8, and 9 the results of analyses with the *A. niger*, chemical, Neubauer, and Mitscherlich methods are given for a large number of soils.

Comparison with a chemical method. It is apparent that, in general *A. niger* absorbs more than the replaceable potassium, excepting in cases where the soil contains an abnormally high content. In these cases there is, apparently, more replaceable potash present than the mold is capable of utilizing. As indicated in figure 2, there exists a fairly good correlation between replaceable potash and that determined by the *A. niger* method.

Comparison with the Neubauer method. *A. niger* absorbs considerably more potassium than the rye seedlings in the Neubauer method, especially when the available potassium content is low. High soluble salt content of the soil tends to give somewhat higher values with *A. niger*. Similarly, with peat and muck soils, the *A. niger* method gives slightly higher results, but usually not

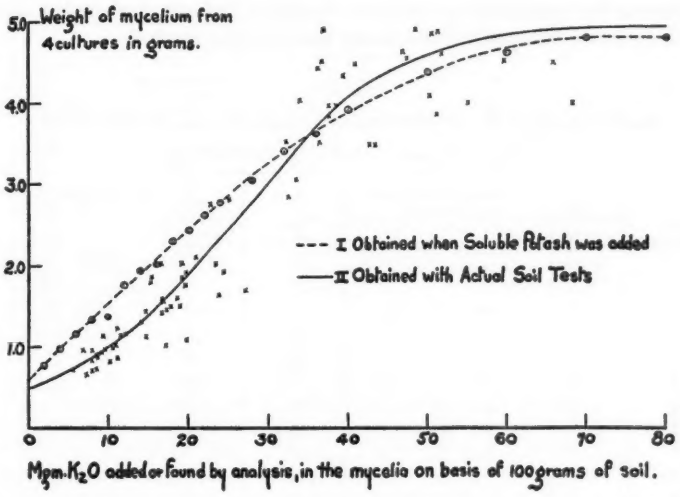


FIG. 1. RELATION OF WEIGHTS OF MYCELIUM TO SOLUBLE POTASH ADDED IN NUTRIENT MEDIA (CURVE I); RELATION OF WEIGHTS OF MYCELIUM TO POTASH EXTRACTED FROM DIFFERENT SOILS BY THE MOLD (CURVE II)

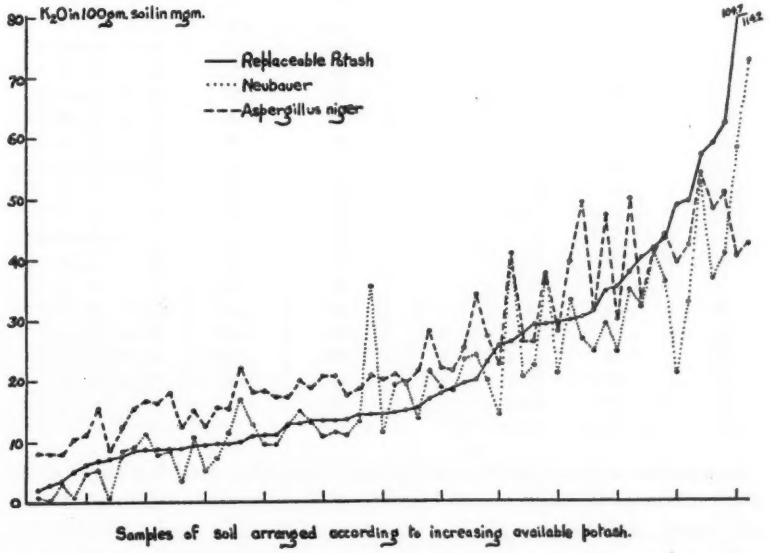


FIG. 2. COMPARISON OF AVAILABLE POTASH BY THREE METHODS IN 61 SAMPLES OF SOIL FROM VARIOUS PARTS OF UNITED STATES

in excess of the replaceable potassium. As shown in figure 2, there is a rather good correlation between the Neubauer and *A. niger* methods.

TABLE 7

Available potash in 62 soils determined with the A. niger and chemical methods

(Curve II, figure 1 used in *A. niger* method)

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	AVAILABLE K_2O PER 100 GM. SOIL		SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	AVAILABLE K_2O PER 100 GM. SOIL	
		A. niger method	Chemical method (replaceable)			*A. niger* method	Chemical method (replaceable)
	gm.	*mgm.*	*mgm.*		*gm.*	*mgm.*	*mgm.*
1	0.71	6.0	0.7	32	1.38	14.8	10.8
2	0.73	6.1	1.1	33	1.35	14.5	10.8
3	0.86	8.2	2.0	34	1.30	14.0	11.2
4	0.80	7.5	3.5	35	1.40	15.1	11.8
5	0.91	9.0	4.6	36	1.45	15.6	12.0
6	0.89	8.8	4.7	37	1.50	16.1	12.6
7	0.94	9.4	5.1	38	1.50	16.1	12.9
8	0.97	9.8	5.5	39	1.61	17.1	13.1
9	0.94	9.4	5.5	40	1.58	16.8	13.6
10	1.02	10.4	5.8	41	1.54	16.4	13.8
11	1.23	13.2	6.1	42	1.63	17.2	14.0
12	1.18	12.6	6.3	43	1.66	17.8	14.1
13	1.22	11.0	6.5	44	1.88	19.8	14.2
14	1.12	11.8	7.0	45	1.91	20.0	14.7
15	1.08	11.4	7.2	46	1.80	19.1	15.0
16	1.15	12.2	7.2	47	1.75	18.6	15.2
17	1.24	13.3	7.6	48	1.78	18.8	15.5
18	1.26	13.6	7.7	49	1.93	20.2	15.5
19	1.36	14.6	7.8	50	1.88	19.8	15.7
20	1.34	14.4	8.3	51	2.00	20.9	16.7
21	1.33	14.3	8.3	52	1.85	19.6	19.0
22	1.16	12.3	8.3	53	1.73	18.5	19.2
23	1.20	12.8	8.7	54	1.95	20.3	19.5
24	1.34	14.4	8.8	55	2.12	22.0	20.0
25	1.23	13.2	8.8	56	2.14	22.2	20.1
26	1.48	15.9	8.9	57	2.23	22.9	20.7
27	1.41	15.2	8.95	58	2.17	22.4	20.9
28	1.35	14.5	9.4	59	2.27	23.2	21.4
29	1.34	14.4	9.7	60	2.34	23.8	22.6
30	1.40	15.1	9.8	61	2.54	25.6	26.1
31	1.39	14.9	9.95	62	3.52	34.4	41.9

Comparison with the Mitscherlich method. The Mitscherlich method gives lower values for available potash than the *A. niger* method. However, in the soils tested, both methods agree in that none of the soils need potash fertilization

TABLE 8

Available potash in 61 soils according to the A. niger, Neubauer, and chemical methods

(Curve II, figure 1 used in *A. niger* method)

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	AVAILABLE K_2O PER 100 GM. SOIL			SOLUBLE SALT CONTENT OF SOIL
		A. niger method	Neubauer method	Chemical method (replaceable)	
	gm.	*mgm.*	*mgm.*	*mgm.*	*p.p.m.*
1801M*	0.85	8.1	1.8	2.1	111
1800	0.84	8.0	1.2	2.9	165
83	0.85	8.0	3.1	3.5	....
1799	1.10	10.4	1.8	5.0	70
1798	1.09	11.3	4.8	6.1	82
1738	1.46	15.6	5.4	6.9	173
1649M	0.87	8.6	0.6	7.2	1115
1754	1.16	12.4	8.5	7.7	181
1638	1.48	15.7	9.1	8.5	235
1632	1.57	16.8	11.5	8.7	151
1635	1.54	16.4	7.9	8.8	192
1634	1.70	18.0	8.5	8.8	270
1646M	1.18	12.4	3.6	8.9	413
1637	1.42	15.2	10.9	9.5	221
1843	1.16	12.4	5.4	9.6	413
1845	1.49	15.8	7.3	9.8	199
1645	1.46	15.6	11.5	9.8	197
1641	2.13	22.0	16.9	10.0	200
1643	1.69	18.0	12.7	10.9	224
1631	1.71	18.2	9.7	11.1	156
1647	1.62	17.3	9.7	11.2	413
1644	1.61	17.2	12.7	12.8	154
1640	1.88	20.0	15.1	12.8	275
1648M	1.77	18.8	13.3	13.4	616
1639	2.00	20.7	10.9	13.4	181
1740	2.01	20.8	11.5	13.4	140
1633M	1.64	17.6	9.1	13.6	200
1650M	1.72	18.4	13.3	14.3	586
1847	2.00	20.8	35.7	14.3	1183
1577M	1.92	20.2	11.5	14.4	1234
1642	2.02	21.0	19.4	14.7	419
84	1.87	19.6	19.8	15.0	....
1636	2.09	21.8	13.9	15.7	192
1844	2.86	28.2	21.8	17.0	346
1651M	2.13	22.0	18.8	17.9	726
1581M	2.10	21.8	18.2	18.5	702
1737	2.52	25.4	23.6	19.8	273
1756M	3.52	34.2	24.2	20.0	306
1739	2.76	27.4	20.0	23.2	275
1593M	2.19	22.6	14.5	25.9	3046
1850	4.00	39.8	41.1	26.3	381
1489P†	2.65	26.5	20.6	27.8	3510

* M = Muck.

† P = Peat.

TABLE 8—*Concluded*

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	AVAILABLE K_2O PER 100 GM. SOIL			SOLUBLE SALT CONTENT OF SOIL
		A. niger method	Neubauer method	Chemical method (replaceable)	
	gm.	*mgm.*	*mgm.*	*mgm.*	*p. p. m.*
1585P	2.64	26.4	22.4	29.4	2335
1846	3.84	37.8	36.3	29.4	464
1578M	2.84	28.1	21.2	29.7	3272
1753	4.00	39.8	33.3	30.0	418
1849	4.60	49.6	26.6	30.5	726
1576M	3.22	31.4	24.8	31.4	1847
1755	4.50	47.2	29.6	34.8	200
1588P	3.05	30.0	24.8	35.6	3102
1848	4.61	50.0	35.1	37.9	464
1594P	3.44	33.6	32.1	40.4	1528
1595M	4.10	41.0	41.7	41.9	702
1752	4.32	44.2	36.3	43.6	224
1579P	4.00	39.6	21.2	49.0	3510
1592P	4.20	42.4	32.7	49.8	3272
1580P	4.74	54.4	52.6	57.2	1561
1590P	4.54	48.2	36.9	59.1	2835
1586P	4.65	51.2	41.1	62.4	2335
1582P	4.06	40.4	58.3	104.7	5095
1584P	4.19	42.4	72.6	114.2	3810

TABLE 9

Available potash in 20 soils, determined with the A. niger, chemical, and Mitscherlich methods

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	AVAILABLE K_2O PER 100 GM. SOIL			
		A. niger method		Chemical method (replaceable)	Mitscherlich method
		By actual mycelium analysis	By curve interpolation		
	gm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*
63	3.85	37.69	37.8	19.15	19.64
64	4.89	50.78	62.8	40.25	25.53
65	4.84	50.25	60.0	31.40	98.20
66	4.48	40.57	47.0	29.95	25.53
67	4.42	36.11	46.2	27.85	23.57
68	3.97	37.70	39.2	21.50	23.57
69	3.95	38.48	39.0	19.50	29.46
70	4.35	39.26	44.6	28.50	19.64
71	4.90	36.64	68.0	30.65	25.53
72	4.28	34.02	43.6	26.00	31.42
73	1.89	19.36	20.0	13.15	31.42
74	4.90	48.16	68.0	29.25	24.53
75	4.55	47.11	48.4	29.45	27.50
76	2.72	16.60	22.1	19.70	33.39
77	2.03	16.60	21.2	10.90	29.46
78	3.44	43.45	35.6	38.80	28.00
79	3.50	32.36	34.2	38.20	19.15
80	2.80	25.12	27.8	21.60	19.64
81	4.60	51.86	49.8	46.10	24.06
82	3.48	42.67	34.0	45.20	18.17

Comparison with field tests. In table 10 are given the results of the *A. niger* and chemical methods when used with a group of soils that have been tested in the field for potash needs. The response of alfalfa to potash fertilization on these soils is also given. It will be noted that the lower values in the *A. niger* method, and also in the chemical method, correspond with the soils that respond to potash fertilization.

Practical application

From these data it may be concluded that the need of potash fertilization is indicated when the potash absorbed by *A. niger* is less than 15 mgm. per 100 gm. of soil. If the amount is 15 to 20 mgm., a light potash application may be beneficial, and when it is more than 20 mgm., there is probably no need for potash fertilization, excepting for certain special crops and conditions.

TABLE 10

Comparison of available potash by A. niger and chemical methods, with response of alfalfa in field to potash fertilization

SOIL NUMBER	TOTAL WEIGHTS OF MYCELIUM FROM 4 CULTURES	AVAILABLE K_2O PER 100 GM. SOIL		INCREASES PER ACRE OF ALFALFA HAY DUE TO POTASH FERTILIZATION
		By *A. niger* method curve interpolation	By chemical method (replaceable)	
	gm.	*mgm.*	*mgm.*	*pounds*
3	0.98	10.0	2.0	408
10	1.32	14.2	5.8	621
12	1.34	14.4	6.3	543
14	1.68	18.0	7.0	193
26	1.72	18.3	8.9	122
28	1.62	17.4	9.4	121
38	1.74	18.4	12.9	98
39	1.94	20.3	13.1	0
43	2.30	21.8	14.1	46
45	2.33	23.6	14.7	65
47	2.45	24.8	15.2	0
51	2.05	21.4	16.7	0
54	2.51	25.3	19.5	0
61	2.81	27.8	26.1	0

SUMMARY

In a study of the *A. niger* method for the determination of available potassium in soils, attention was given to the following points: (*a*) adaptability of various strains of *A. niger;* (*b*) maintenance of stock cultures; (*c*) influence of reaction, various salts, acid radicals and minor soil constituents and stimulants; (*d*) application of the method to the quantitative determination of available potassium by means of analysis of the mycelium for potassium, and by interpolation on a specially constructed curve; and (*e*) comparison of results

with other methods and field tests. The results of this study may be summarized as follows:

Two strains of *A. niger*, one obtained from Weihenstephan, Germany, and which has been used by Niklas, and one from the stock cultures at this station gave equally satisfactory results. The strain from Germany was chosen for the work reported here because of its already wide use in this connection by Niklas and others.

It was found that when the $CaCO_3$ content of the soil exceeded 1 per cent it is necessary to add additional acid to the cultures in order to maintain an optimum pH for the germination of the mold spores and to prevent bacterial growth. A simple method for determining the $CaCO_3$ content of the soil is described.

It was found that various Ca, Mg, and Na salts, acid radicals of potassium salts, and minor soil constituents and stimulants do not influence the growth of the mold sufficiently to interfere seriously with the results.

The method can be applied to the quantitative determination of available potassium by means of analysis of the mycelium for potassium or more conveniently by interpolation of the weight of the mycelium on a curve which has been especially constructed for this purpose.

The results with the method compare very favorably with the chemical method, the Neubauer method, Mitscherlich's method, and field tests.

It is concluded that the test is simple and reliable and may be used in a practical way for the determination of potash needs of soils.

REFERENCES

(1) BENECKE, W., AND SÖDING, H. 1928 Beiträge zum Ausbau der mikrobiologischen Bodenanalyse. *Ztschr. Pflanzenernähr. u. Düngung* (A) 10: 129–159.

(2) BUTKEWITSCH, W. 1909 Die Kultur des Schimmelpilzes *Aspergillus niger*, als Mittel zur Bodenuntersuchung. *Zhur. Opytn. Agron.* (*Russian Jour. Expt. Landw.*) 10: 136–141.

(3) ECKSTEIN, O., JACOB, A., UND ALTEN, F. 1931 Arbeiten über Kalidüngung. *Ernähr. Pflanze* 27: 497–499.

(4) FREY, A., AND POSCHENRIEDER, H. 1932 Beziehungen zwischen Säurebildung und Mycelgewichtsbeeinflussung bei *Aspergillus niger*. *Arch. Mikrobiol.* 3: 409–421.

(5) KIESSLING, E. 1931 Untersuchungen über den Kalihaushalt eines langjährig einseitig gedüngten Versuchsfeldbodens mittels der Aspergillusmethode nach Niklas-Poschenrieder-Trischler. *Ztschr. Pflanzenernähr. u. Düngung* (A) 19: 241–250.

(6) KIESSLING, E. 1931 Über die Beeinflussung der Aspergillusmethode durch Humussäure. *Ztschr. Pflanzenernähr. u. Düngung* (A) 21: 86–104.

(7) KOSZELESKII, A. K. 1909 Die Bestimmung der Phosphorsäure in Lösungen mittels der Kultur von *Aspergillus niger*. *Zhur. Opytn. Agron.* (*Russian Jour. Expt. Landw.*) 10: 321–354; 449–483.

(8) LOHMANN, P. 1931 Vergleichende Untersuchungen über die Bestimmung des Gehaltes von Böden an Pflanzennährstoffen. *Bot. Arch.* 31: 489–518.

(9) MEVIUS, W. 1927 Reaction des Bodens und Pflanzenwachstum. *Naturw. u. Landw.* 11: 1–153, Verlag F. P. Datterer u. Cie. Freising-München (1927).

(10) NIKLAS, H., AND POSCHENRIEDER, H. 1932 Die Ausführung der Aspergillusmethode zur Prüfung auf Kali. *Ernähr. Pflanze* 28: 86–88.

(11) NIKLAS, H., POSCHENRIEDER, H., AND FREY, A. 1931 Untersuchungen zur Feststellung der Magnesiadüngebedürftigkeit von Böden mittels *Aspergillus niger*. *Ernähr. Pflanze* 27: 465–470.

(12) NIKLAS, H., POSCHENRIEDER, H., AND TRISCHLER, J. 1930 Die Kultur des Schimmelpilzes *Aspergillus niger* zur biochemischen Bestimmung der Kali- und Phosphorsäurebedürftigkeit der Böden. *Ernähr. Pflanze* 26: 97–103.

(13) NIKLAS, H., POSCHENRIEDER, H., AND TRISCHLER, J. 1930 Die Bestimmung des Kalidüngebedürfnisses der Böden mittels *Aspergillus niger*. *Ernähr. Pflanze* 26: 339–341.

(14) NIKLAS, H., POSCHENRIEDER, H., AND TRISCHLER, J. 1930 Eine neue mikrobiologische Methode zur Feststellung der Düngebedürftigkeit der Böden. *Ztschr. Pflanzenernähr. u. Düngung* (A) 18: 129–157.

(15) NIKLAS, H., POSCHENRIEDER, H., AND TRISCHLER, J. 1931 Eine neue mikrobiologische Methode zur Feststellung der Düngebedürftigkeit der Böden. *Arch. Pflanzenbau* 5: 451–485.

(16) NIKLAS, H., POSCHENRIEDER, H., AND VILSMEIER, G. 1930 Weitere Ergebnisse zur Bestimmung der Kalibedürftigkeit der Böden mittels *Aspergillus niger*. *Arch. Pflanzenbau*. 5: 152–165.

(17) NIKLAS, H., VILSMEIER, G., AND POSCHENRIEDER, H. 1932 Der Einfluss des Kalkgehaltes auf das Aspergilluswachstum bei der Prüfung des Kalidüngebedürfnisses der Böden. *Ztschr. Pflanzenernähr. u. Düngung* (A) 24: 167–178.

(18) PANTANELLI, E. 1924 Biochemical determination of the available phosphates in soil. *Actes IV. Confer. Internatl. Pedologie, Rome* 3: 232–236.

(19) RIPPEL, K. 1931 Quantitative Untersuchungen über die Abhängigkeit der Stickstoffassimilation von der Wasserstoffionenkonzentration bei einigen Pilzen. *Arch. Mikrobiol.* 2: 72–135.

(20) SEIDEL, K. 1931 Eine neue mikrobiologische Methode zur Beurteilung der Nährstoffverhältnisse eines Bodens. *Arch. Pflanzenbau* 6: 536–576.

(21) SIMAKOVA, T., AND BOVSCHIK, G. 1932 Über die mikrobiologische Methode zur Bestimmung des Phosphorbedürfnisses des Bodens mittels *Aspergillus niger*. *Ztschr. Pflanzenernähr. u. Düngung* (A) *24*: 341–353.

(22) SMITH, F. B., BROWN, P. E., AND SCHLOTS, F. E. 1932 A comparison of the Niklas and Truog methods for the determination of available phosphorus in soils. *Jour. Amer. Soc. Agron.* 24: 452–459.

(23) STEINBERG, R. A. 1919 A study of some factors in the chemical stimulation of the growth of *Aspergillus niger*. *Amer. Jour. Bot.* 6: 330–372.

(24) TRISCHLER, J. 1931 Ernährungsphysiologische Studien an dem Schimmelpilz *Aspergillus niger*, als Grundlage zur Feststellung des Kalidüngebedürfnisses der Böden. *Arch. Pflanzenbau* 7: 39–78.

(25) VAGELER, P., AND ALTEN, F. 1931 Böden des Nil und Gash IV. *Ztschr. Pflanzenernähr. u. Düngung* (A) 22: 1–77.

(26) VANIK, M. 1931 Untersuchungen über den Einfluss verschiedener Faktoren auf die Aspergillusmethode zur Feststellung des Kalidüngebedürfnisses der Böden. Dissertation Tech. Hochschule München.

(27) VILSMEIER, G. 1932 Beiträge zu den chemischen Grundlagen der Aspergillusmethode. *Arch. Pflanzenbau* 8: 683–718.

(28) VOLK, N. J., AND TRUOG, E. 1933 A rapid method for determining the available potassium of soils. Unpublished.

(29) WALLACE, G. I., AND TANNER, F. W. 1931 Effect of heat on mold spores. *Proc. Soc. Exp. Biol. Med.* 28: 970–972.

PLATE 1

GROWTH OF A. NIGER CULTURE WITH DIFFERENT SOILS

1—Plainfield sand—contains 0.7 mgm. replaceable K_2O per 100 gm. soil. Needs potash.

2—Sandy loam—contains 5.8 mgm. replaceable K_2O per 100 gm. of soil. Needs potash.

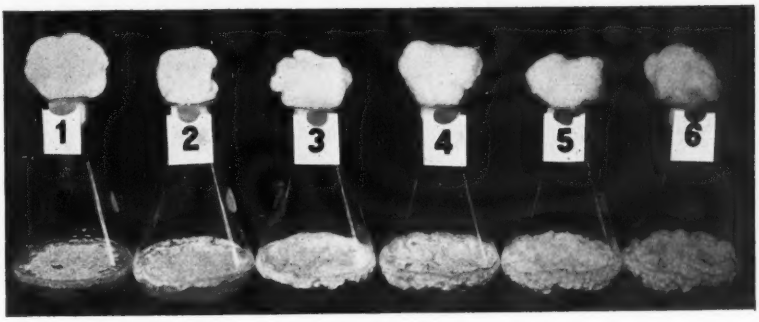
3—Marshall silt loam—contains 11.8 mgm. replaceable K_2O per 100 gm. of soil. Slight need of potash.

4—Silt loam—contains 19.8 mgm. replaceable K_2O per 100 gm. of soil. Does not need potash.

5—Silt loam—contains 37.9 mgm. replaceable K_2O per 100 gm. of soil. Does not need potash.

6—Soil from Prof. Mitscherlich, Germany—contains 40.25 mgm. replaceable K_2O per 100 gm. soil. Does not need potash.

PLATE 1



PHOTONITRIFICATION IN SOIL

N. R. DHAR, A. K. BHATTACHARYA, AND N. N. BISWAS

University of Allahabad, India

Received for publication August 27, 1932

In previous publications[1] from these laboratories a new view on the process of nitrification in soil has been advanced and supported by experiments. It has been shown that the process of nitrification in soil is mainly due to the oxidation of ammonium salts to nitrite by air in the presence of sunlight. In other words, according to our view, nitrification in the soil, especially in the tropics, is more photochemical in nature than bacterial.

In this paper, we are submitting the results of our experiments on nitrification in soil effected by sunlight. The experiments were carried on as follows:

Soil was collected from a hole dug 9 inches deep in the grass land at a particular spot in the laboratory compound. The soil was crushed, passed through a sieve with 1 mm. bore, and was air dried at 30°. Of this soil 2,000 gm. was mixed with 20 gm. of ammonium salts and 750 cc. of water. The whole mixture was kept in both earthen and large glass jars having a capacity of 4,000 cc. and exposed to sunlight. Water was daily added in order to make up for the water lost by evaporation. The vessels were weighed every week to test for the constancy in weight. The soil was well stirred every morning before exposure. Blank experiments were also carried on in the dark by covering the glass jars with a thick layer of black Japan enamel and the earthen pots with a tin lid blackened by black Japan. For the experiments in the dark, these vessels were also placed in the sun to have the same temperature as those exposed to the sun. After the exposure was completed 50 gm. of the soil was taken out and the ammonia was estimated by adding potassium hydroxide to the soil and distilling the liberated ammonia, which was absorbed by a standard solution of sulfuric acid. At the end of the experiment, this sulfuric acid was titrated against the standard solution of caustic potash and thus the amount of ammonia absorbed by sulfuric acid was found. Then another 50 gm. of the soil was taken and treated with Devarda's alloy for estimating the ammonium salt and the nitrites and nitrates.

Table 1 shows the results obtained with soil and ammonium salts exposed in earthen vessels for 160 hours. These experiments carried on in earthen

[1] Dhar, N. R., and Rao, G. G. 1932 Nitrification in soil and air—a photochemical reaction. *Jour. Indian Chem. Soc.* 9.

Rao, G. G., and Dhar, N. R. 1931 Photosensitized oxidation of ammonia and ammonium salts and the problem of nitrification in soils. *Soil Sci.* 31: 379.

pots were not very satisfactory because the pots were porous and, as a result, a good deal of the ammonium salts percolated and came out on the outer surface of the pots.

The results given in table 2 were obtained in glass vessels after 160 hours' exposure to sunlight with loose covers. As the percentage of oxidation was

TABLE 1

Nitrification of soil exposed in earthen vessels for 160 hours

NUMBER	CONDITION	AMOUNT OF SALT ADDED	UNCHANGED AMOUNT OF SALT	AMOUNT OF OXIDIZED SALT	PERCENTAGE OXIDIZED
1	Sunlight	20 gm. ammonium chloride	13 gm. ammonium chloride	6.7 gm. ammonium chloride	33.5
2	Dark	20 gm. ammonium chloride	18.7 gm. ammonium chloride	1.3 gm. ammonium chloride	6.5
3	Sunlight	20 gm. ammonium chloride to heated soil	15.5 gm. ammonium chloride	4.4 gm. ammonium chloride	22.0
4	Sunlight	20 gm. ammonium sulfate	18.75 gm. ammonium sulfate	1.2 gm. ammonium sulfate	6.0
5	Dark	20 gm. ammonium sulfate	20 gm. ammonium sulfate	nil	nil
6	Sunlight	20 gm. ammonium phosphate	16.6 gm. ammonium phosphate	3.3 gm. ammonium phosphate	16.5
7	Dark	20 gm. ammonium phosphate	20 gm. ammonium phosphate	nil	nil

TABLE 2

Nitrification of soil exposed in glass vessels for 160 hours

NUMBER	CONDITION	AMOUNT OF SALT ADDED	UNCHANGED AMOUNT OF SALT	AMOUNT OF OXIDIZED SALT	PERCENTAGE OXIDIZED
1	Sunlight	20 gm. ammonium chloride	18.64 gm. ammonium chloride	1.33 gm. ammonium chloride	6.65
2	Sunlight	20 gm. ammonium phosphate	17.54 gm. ammonium phosphate	2.44 gm. ammonium phosphate	12.2
3	Dark	20 gm. ammonium phosphate	19.8 gm. ammonium phosphate	0.2 gm. ammonium phosphate	1.0
4	Sunlight	20 gm. ammonium sulfate	19.6 gm. ammonium sulfate	0.3 gm. ammonium sulfate	1.5
5	Dark	20 gm. ammonium sulfate	20 gm. ammonium sulfate	nil	nil

not high after 160 hours' exposure, the vessels were again exposed to sunlight for a much longer period. The results given in table 3 were obtained after a total exposure to sunlight for 700 hours in the months of May, June, and July, 1932.

The tabulated results show conclusively that on exposing the ammonium salt solutions to light in contact with the soil, an appreciable amount of the salts are photochemically oxidized in air after an exposure for 160 hours but the oxidation is greatly increased after 700 hours' exposure, as shown in table 3. Ammonium phosphate undergoes oxidation to a greater extent than the other ammonium salts under smilar conditions. The oxidation in the vessels kept in the dark under identical conditions is very small and in some cases negligible.

If nitrification is mainly bacterial, as is generally believed, the ammonium salts in the vessels kept in the dark should have undergone appreciable oxidation. But the results show that the dark oxidation is exceedingly small in comparison with the photochemical oxidation. Moreover, even with the

TABLE 3

Nitrification of soils exposed to sunlight for 700 hours

NUMBER	CONDITION	AMOUNT OF SALT ADDED	UNCHANGED AMOUNT OF SALT	AMOUNT OF OXIDIZED SALT	PERCENTAGE OXIDIZED
1	Sunlight	20 gm. ammonium chloride	3.5 gm. ammonium chloride	15.25 gm. ammonium chloride	80.1
2	Dark	20 gm. ammonium chloride	17.25 gm. ammonium chloride	0.85 gm. ammonium chloride	4.8
3	Sunlight	20 gm. ammonium sulfate	17.25 gm. ammonium sulfate	2.62 gm. ammonium sulfate	13.2
4	Dark	20 gm. ammonium sulfate	20 gm. ammonium sulfate	nil	nil
5	Sunlight	20 gm. ammonium phosphate	2 gm. ammonium phosphate	16.5 gm. ammonium phosphate	89.0
6	Dark	20 gm. ammonium phosphate	18.5 gm. ammonium phosphate	0.25 gm. ammonium phosphate	1.4
7	Sunlight	10 gm. ammonium phosphate in 1,000 gm. of heated soil	1.38 gm. ammonium phosphate	8.37 gm. ammonium phosphate	85.8

sterilized (by heating for 48 hours at 150°) soil ammonium phosphate undergoes considerable oxidation in the presence of sunlight. The oxidation of ammonium phosphate in the presence of sunlight is practically the same in the sterilized and in the unsterilized soils. It appears, therefore, that nitrification, especially in tropical countries, is more a photochemical than a bacterial process. It will be of interest to note that the ammonium salts are photochemically oxidized to nitrites and not to nitrates in the soil. It is well known that nitrates are converted into nitrites in light.

We have carried on similar experiments with urea, 10 gm. of which were mixed with 1,000 gm. of the same soil and one glass jar was exposed to sunlight for 540 hours under the same conditions as in the case of the ammonium salts. The following results were obtained: amount of urea added, 10 gm.; amount of

unchanged ammonia, 4.7 gm.; amount of oxidized ammonia, 0.7 gm. Hence the percentage of ammonification is 54 and the percentage of its subsequent oxidation to nitrite is 15.

From our experiments, it appears that ammonification is also markedly photochemical in nature. We have been able to convert several nitrogenous compounds into ammonia by exposing the solutions of these compounds to light. Hence it appears to us that in the soil the ammonification of nitrogenous compounds and the subsequent oxidation of ammonium salts to nitrites are markedly accelerated by light, and the process of soil nitrification is more of photochemical than of bacterial origin.

Further experiments on this line on sterilized and unsterilized soils are in progress.

SUMMARY

On exposing ammonium salt solutions mixed with soil to sunlight in presence of air for 700 hours, the amounts of the ammonium salts oxidized are as follows:

	per cent
Ammonium chloride	80
Ammonium phosphate	89
Ammonium sulfate	13.2

With sterilized soil and ammonium phosphate under identical conditions the percentage oxidation was 85.8.

The amount of oxidation by an exposure of 160 hours was less than in the previous case.

The oxidation in the vessels kept in the dark under identical conditions is very small and in some cases negligible.

It is evident from these and other experimental observations that nitrification in soil, especially in tropical countries, is a more photochemical than a bacterial process.

A SOIL TEMPERATURE INSTALLATION[1]

G. ALLEN MAIL[2]

Montana Agricultural Experiment Station

Received for publication August 29, 1932

The importance of soil temperature as an ecological factor influencing both plant and animal life has come only recently to be recognized. Although there are over 1,000 stations in the United States where meteorological observations are made, and in some cases air temperature records have been kept for over 35 years, it is doubtful whether there are more than 20 localities where soil temperature data have been collected over a period of 10 years.

There are many different methods of taking soil temperatures but one of the most adaptable and accurate is by the use of thermocouples, which are ideally suited for the reading of temperatures in inaccessible places such as in insect bodies, under the bark of trees, and at various depths in the soil. For measuring precipitation, and for taking air temperatures and other meterological data, the government weather stations are equipped with standard apparatus. Soil temperature records from different parts of the country, to be strictly comparable, should likewise be obtained, as far as possible, with a similar technique. There are, of course, many factors entering into the taking of soil temperatures which do not need to be considered in the taking of air temperatures. Slope exposure, for example, is, according to Shreve (3), of great importance at high altitudes and high latitudes but has little importance at sea level at low latitudes. The color, texture, and moisture content of the soil, and the character of the plant cover are among the most important factors to be considered, but these variables afford all the more pressing arguments for the adoption of a standard method. Writing of soil temperatures in the United States, Fitton and Brooks (1) observe, "The scantiness of the material now available emphasizes the need for many additional observations of soil temperatures, which should be made under conditions as uniform as possible."

Many of the records now available are for short periods of time, covering only the growing season of crops being studied or other seasons of the year in which the investigators were interested. Soil records, to be of the greatest value, should be taken over long periods of years. It is with this end in view that the writer has undertaken the installation of a soil temperature apparatus which is designed to give many years of service. For the past 2 years soil tempera-

[1] Montana State College, Agricultural Experiment Station, Paper 11, Journal Series.

[2] The writer wishes to express his indebtedness to the Mountain States Telephone and Telegraph Company for many courtesies extended in connection with this study.

tures have been taken at the Montana Agricultural Experiment Station, a modification of the set-up used at Minnesota by the writer (2) being used. This, however, was of too temporary a nature, being designed solely for a short-time investigation.

SOIL TEMPERATURE APPARATUS

The recording portion of the system is located inside a heated one-story wooden building. This consists of a terminal box, a switch board, galvanometer, potentiometer, and a Dewar flask containing ice and water (plate 1). The terminal box, in which all outside wires are soldered to numbered brass studs, is filled with insulating compound. The galvanometer is a Leeds and Northrup No. 2420b. of a sensitivity per millimeter division of 25 microvolts.

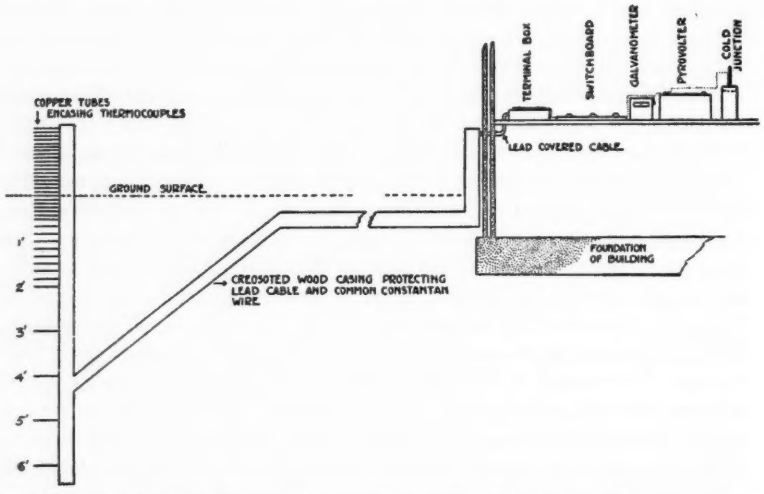


FIG. 1. PLAN SHOWING GENERAL ARRANGEMENT OF SOIL TEMPERATURE INSTALLATION

The potentiometer is a standard Northrup Pyrovolter, catalog No. 160, Range A 0–25°C. 0–1 mv. Range B 0–125°C. 0–5 mv.

The connection from the terminal box to the buried part of the system consists of a lead-covered telephone cable of 52 paper insulated 22-gauge copper wires. The buried portion of the system is 30 feet from the building in a grass lawn. The cable lies in a wooden casing constructed of 1-inch soft pine which, like all the wooden construction, has been treated with two coats of hot creosote. The buried couples are constructed of 32-gauge copper and constantan enameled and single silk insulated wires. All the wiring has been done on a piece of hard wood 1 inch by 4 inches by 6 feet, the thermocouples projecting 6 inches through $\frac{3}{16}$-inch holes bored at the required depths. In order to hold the couples out horizontally from the board and to maintain their relative dis-

tance from each other, as well as to protect them from corrosion, $\frac{3}{16}$-inch copper tubes 7 inches long, sealed at one end and threaded at the other, were slipped over them and screwed into the wood. The wiring being completed and the protecting copper tubes placed in position, the 32-gauge wires were soldered to those of the cable from the recording instruments. This wired hardwood strip was then screwed with flat headed brass screws to a square wooden casing with an inside diameter of 2 inches of which it formed the fourth side. One end being plugged, hot insulating compound, such as is used in transformers, was

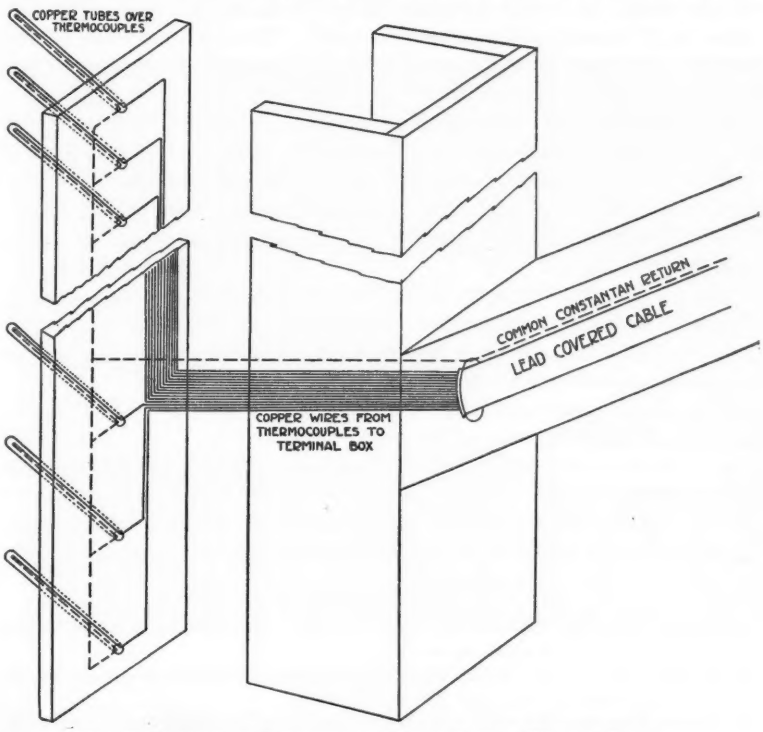

COPPER TUBES OVER THERMOCOUPLES
COMMON CONSTANTAN RETURN
LEAD COVERED CABLE
COPPER WIRES FROM THERMOCOUPLES TO TERMINAL BOX

FIG. 2. DETAILS OF CONSTRUCTION INSIDE BURIED WOODEN CASING

poured into the other end thus making the system quite water-tight. There was a chance for error because the lead cable was buried near the surface and might conduct heat to the couples. To obviate this, the cable, about 6 feet from the couples, was inclined downward, and the connections were made with the 32-gauge wires inside their protecting casing at 4 feet in depth. A hole 6 feet deep was dug, with one vertical side. Each foot of earth removed was kept in a separate pile so that it could be returned in the same order in which it was removed. Holes just large enough to receive the copper tubes were bored in

the undisturbed face of the excavation. The wired casing was then placed in position and the hole filled (fig. 1).

The depths at which temperatures are being taken are soil surface, every inch for the first 6 inches, every 2 inches from 8 to 24 inches, and at 3, 4, 5, and 6 feet. There are also couples at inch intervals to a height of 18 inches above ground, the casing extending that distance upward.

The common constantan return wire from the buried thermocouples to the instrument was run with the cable, but not in contact with it, in its protecting wooden casing, no further insulation being considered necessary. The diagram (fig. 2) shows how the system was wired. Where subzero temperatures are likely to be encountered, a double-pole double-throw reversal switch will facilitate making the readings.

A cheaper but satisfactory instrument which may be used in place of the pyrovolter is a Leeds and Northrup Arsonval galvanometer List F4445 Type P with a resistance of 1,100 ohms. This is a wall type with a reflecting mirror and can be used with a lamp and scale or a telescope and scale reading device. In using this instrument in connection with soil temperature work, the galvanometer scale must, of course, be calibrated. This, however, is a simple procedure and, since the temperature scale is a straight line, the readings of deflections can readily be resolved into temperatures. Should the galvanometer scale be of too short a range, a resistance may be introduced which will keep the deflections within measurable range.

Care must be observed in using a galvanometer as part of this installation, as there are sources of error which must be allowed for. Each thermocouple ought to be accurately calibrated, as the resistance of the wires varies according to their length. This is especially important if a low resistance galvanometer is used. Of course, if the variation in the length of the wires is not greater than 5 or 6 feet the error might be so small as to be negligible in this particular work.

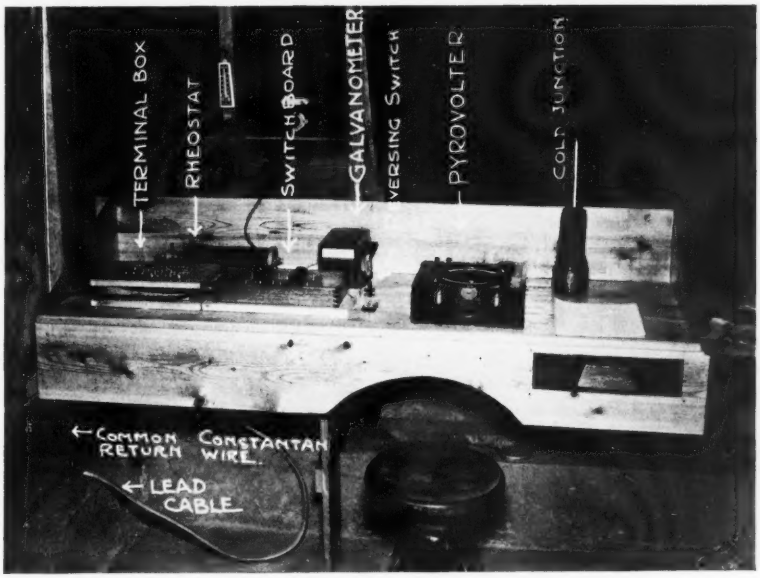
REFERENCES

(1) FITTON, EDITH M., AND BROOKS, CHAS. F. 1931 Soil temperatures in the United States. *Mo. Weather Rev.* 59: 6–16.

(2) MAIL, G. ALLEN 1930 Winter soil temperatures and their relation to subterranean insect survival. *Jour. Agr. Res.* 41: 571–592.

(3) SHREVE, FORREST 1924 Soil temperatures as influenced by altitude and slope exposure. *Ecology* 5: 128–136.

G. ALLEN MAIL



INSTRUMENT BOARD FOR RECORDING SOIL TEMPERATURES

THE DISPERSION OF SOIL-FORMING AGGREGATES[1]

CYRUS L. CLARK[2]

Utah Agricultural Experiment Station

Received for publication September 17, 1932

The primary object in presenting this article is to point out that size distribution is not only dependent on the nature of the soil but also upon the nature of the process used to determine it.

Two arguments are used to support the idea that a unique set of soil particles exist. After a soil has been subjected to a deflocculation treatment, the particles observed under the microscope appear to be unique entities. From this, despite possibilities to the contrary, it is concluded that the essence of the postulate follows. The second is that mechanical analyses derived from standardized processes yield reproducible results. It is generally recognized that all dispersion processes do not accomplish complete deflocculation. Therefore, this argument is not conclusive, for an examination of the literature seems to indicate than an analysis made with any dispersion process is, in a sense, reproducible.

If it were certain that the soil consists of a large number of unambiguously defined particles, and some simple method of treatment might be found to deflocculate the aggregates and place the individual particles in suspension, then it would require nothing essentially new or difficult to make critical analyses of conventional methods. But when the available knowledge of this subject is scrutinized, who is prepared to defend in any satisfactory manner this view?

DUPLICATE SOIL SAMPLES

Soil samples taken from the field at random vary in mechanical composition. For this reason, the analysis is not reproducible unless duplicate samples are employed. Still, it is axiomatic to assume that any given physical system proceeds through a particular set of physical states when it is subjected to an ordered set of definite treatments. If it does not pass through these every time this sequence is applied, failure to reproduce the treatments is regarded as the cause. Soil samples can never be considered more than statistical equivalents. The same thing applies to dispersion processes. Even so, it is expected when a dispersion process is applied to duplicate samples it will pro-

[1] Contribution from department of physics, Utah Agricultural Experiment Station.

[2] Graduate student, department of physics.

Publication authorized by Director, September, 10, 1932

duce practically the same size distribution of particles, because the definition of *duplicate* predicates this reaction.

The definition of *duplicate* may be deduced from the method of preparing such samples. This is done by mixing the soil and then dividing it into the desired number of portions. The amount of mixing is arbitrary, but it must be enough to make them appear uniform in color and texture. Should they be erratic in reacting to applied processes, the conclusion is that they are not duplicates. In like manner when the problem is reversed, similarity in effect upon the senses and in reaction to processes applied establishes whether or not they are duplicates. Therefore, duplicate samples are those which to an arbitrary degree react alike to similar treatments.

THE DISPERSION OF PARTICLES

The purpose of a dispersion process is to separate the aggregates so that the component particles may settle independently. It is important to emphasize the difficulty of distinguishing between the dispersion of crumbs and the disruption of crystal fragments. From the end products it is not possible to distinguish the two. Nevertheless, mechanical shearing stresses of one kind or another are always employed in dispersion.

In chemical processes experiments fail to show unique dispersion limits. Deflocculation is a continuous function of the concentraton of the reagents applied. Keen and Puri (5) found a different (yet definite) maximum deflocculating ability for a number of reagents. From chemical information it is safe to say that for some soils some deflocculating agents will be associated with values corresponding to solution. This variability of the maximum deflocculating ability seems to indicate that as far as chemical processes of this type are concerned, no unique structure is evident.

In order that there be a unique group of particles, it seems that the forces which hold the crystal fragments together in floccules must be small in comparison with those which act between contiguous parts of them. If the dispersive process breaks some of the fragmentary crystals into smaller pieces at the same time that some of the floccules are being separated into components, there is no way of distinguishing between crystalline fragments derived from floccules and those derived from crystal elements.

IMPERFECTIONS OF CRYSTALS

Little difficulty arises in judging with the microscope whether a mass is composed of one or more parts inferred to be crystal fragments. That a dispersion process will resolve this mass into these fragments is not apparent. When a small crystal is examined with a given microscope, the conclusion may not be drawn that there are no imperfections (i.e., cracks, etc.), for a more powerful one might show it to be faulty.

There is evidence from theoretical considerations based on molecular theory and thermodynamics to show that all lattice planes are not bound together

by the same force per unit area (7, 8). This structure accounts for the discrepancy between the calculated and observed breaking strength, the force in mechanical slipping, etc. It is also shown that crystal surfaces are covered by cracks criss-crossing them in an irregular mosaic pattern. Evidence has been obtained of these on etched crystals.

EFFECT OF COMPOSITION AND SIZE ON DISPERSION

Even if it were possible to prove the existence of a unique particle set for all known mineral species, it is still conceivable that the majority of products obtained on mixing these have no unique structure. In order that they have, it is necessary that the applied deflocculation process produce simultaneously complete dispersion in each of the component minerals. For particles of colloidal size, it would be surprising to find such a process. It is, perhaps, because of this fact that investigators in the United States proceed by attempting to disperse all particles having radiuses greater than an arbitrarily set value (6). This evades the difficulties of the colloidal range, but these processes are open to the same criticisms, though perhaps to a different degree, which may be raised against those designed to measure the whole prime structure.

CONCLUSIONS

It would seem that size distributions are comparable only when an inherent unambiguously defined particle set is placed in suspension in every case by the dispersion process. Such a set is assumed to be selected by the standard dispersion processes (3, 4) but the reality of a complete deflocculation seems to be assumed rather than proved. It is not the practice in scientific theory to introduce an unnecessary assumption even though it be designed in anticipation of future results. Theory and fact must grow together, and prime structure does not appear to be necessary to account for experimental facts.

There seems to be ample justification for establishing mechanical analysis upon the functional relationship between dispersion processes and size distribution. It seems that the term *duplicate* may be defined in a practical way so that the arbitrary selection of a dispersion process specifies a particle size distribution for every soil. A unique particle distribution of any kind should be discerned from a study of this relationship.

REFERENCES

(1) HISSINK, D. J. 1927 Methods of mechanical analysis of soils. *Proc. Internat. Soc. Soil Sci.* 1: 137–156 (n.s.).

(2) KEEN, B. A. 1922 Physico-chemical problems relating to the soil (A general discussion held by the Faraday Society). *Trans. Faraday Soc.* 17 (pt. 2).

(3) KEEN, B. A. 1928 First Commission. Soil Mechanics and Physics. *Soil Sci.* 25: 9–20.

(4) KEEN, B. A. 1928 Mechanical analysis: National and international. *Soil Res.* 1: 43–49.

(5) KEEN, B. A., AND PURI, A. N. 1925 *Jour. Agr. Sci.* 15 (pt. 2): 147–161.
(6) OLMSTEAD, L. B., ALEXANDER, L. T., AND MIDDLETON, H. E. 1930 A pipette method of mechanical analysis of soils based on improved dispersion procedure. U. S. Dept. Agr. Tech. Bul. 170.
(7) ZWICKY, F. 1929 On imperfections of crystals. *Proc. Nat. Acad. Sci.* 15: 253–259.
(8) ZWICKY, F. 1929 On mosaic crystals. *Proc. Nat. Acad. Sci.* 15: 816–822.

THE EFFECT OF SOIL MOISTURE ON THE AVAILABILITY OF NITRATE, PHOSPHATE, AND POTASSIUM TO THE TOMATO PLANT[1]

E. M. EMMERT AND F. K. BALL

Kentucky Agricultural Experiment Station

Received for publication August 31, 1932

Considerable study has been made of the effect of soil moisture on nutrients in the soil, but little work has been done to determine the actual uptake of nitrate, phosphate, and potassium from soils of varying moisture content. This paper reports the effect of variations of soil moisture from 10 to 40 per cent on the amount of nitrate, phosphate, and potassium in the lower petioles of tomato plants grown on a uniform soil in which only the moisture was varied. The effect of soil water on moisture in the petioles, on soil nitrate, and on the plant growth, also is reported.

TREATMENTS

Two series of 10, 20, and 40 per cent moisture were made on each of two kinds of soil, making four independent tests of each moisture percentage. The first soil, called "station soil" in the tables, was taken from the horticultural farm. It is a brown to black clay loam. The second soil was made by mixing three-fourths station soil and one-fourth well-rotted compost.

METHOD OF DISTRIBUTING THE SOIL WATER

Hendrickson and Veihmeyer (5) have found it practically impossible to maintain a uniform soil moisture at a certain percentage. Added water caused saturation at certain points without becoming distributed throughout the soil. A special apparatus was set up which was found to distribute the water quite satisfactorily throughout the soil mass. Figure 1 illustrates the method used.

Funnels were connected with the glass tubes and one-third of the required water was added to each of the three soil layers, one-third being distributed over the top, one-sixth added to each of the short tubes, and one-sixth to each of the long tubes. The sand layer permitted the water to spread over the top of the soil as the water was poured in. It then distributed itself quite evenly through the soil. There was no concentration of roots at the sand layers, but the roots were distributed throughout the soil. This proves that the

[1] The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the director.

moisture was distributed throughout the soil mass. Some difficulty was experienced from the clogging of some of the tubes, but a stiff wire plunged through the tubes cleared them so that the water entered readily.

METHOD OF MAINTAINING THE SOIL MOISTURE

The weight of air-dry soil contained in each pot was determined and the percentage of moisture in the air-dry soil was found by oven drying a sample at 100°C. The percentage of water to be added was based on the weight of oven-dry soil. For example, pot 3 contained 6,870 gm. of oven-dry soil. Since

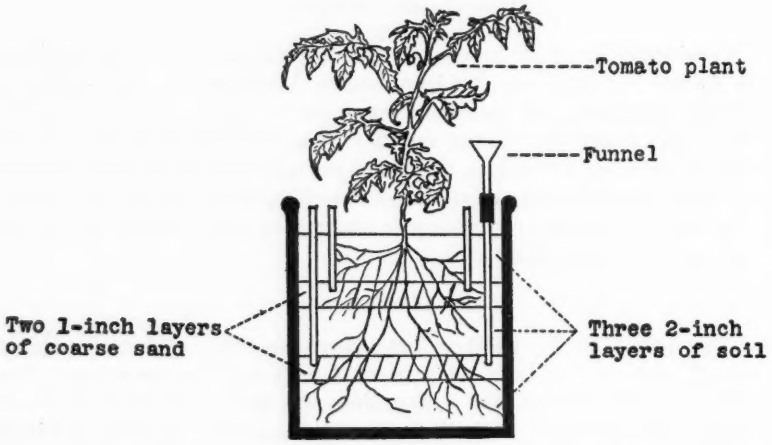


FIG. 1. CROSS SECTION OF 2-GALLON STONE JAR SHOWING APPARATUS FOR DISTRIBUTING WATER THROUGHOUT SOIL

it was to be maintained at 10 per cent moisture, 687.0 gm. of water should be present. The total weight of the complete pot was as follows:

	gm.
Weight of pot	3,880
Weight of sand	2,310
Weight of plant at setting	16
Weight of tubes	23
Weight of oven-dry soil	6,870
Weight of water which should be present	687
Weight at which the pot should be maintained to maintain 10 per cent moisture	13,786

As the plant grew, another plant of similar size was weighed and the weight added. The weight of a wire support was also added when the plant became too tall to remain upright alone.

In order to make sure that 10 per cent was not under the wilting point the wilting point of the soil was determined from the hydroscopic coefficient, as directed by Mosier and Gustafson (6). The wilting coefficient of the soil was found to be 8.2 per cent. When one-fourth compost and three-fourths soil were used the wilting coefficient was found to be 9.5 per cent.

Exactly 10 per cent moisture was not maintained continuously, since the pots were made to the determined weight only every 2 days. During that time about 50 gm. was lost at first. As the plant grew larger, sometimes 150 gm. would be lost, but rarely more than this. When 150 gm. was lost, only 537 gm. of water remained, or a percentage of about 7.8. This means that the moisture went from 10 per cent to about 7.8 per cent during the 2-day period, or that an average of about 9.0 per cent of moisture was actually maintained. The pots that had 20 per cent of moisture lost about 400 gm. every 2 days, when the plants were large. Since 1,374 gm. of water was present originally only 974 gm. remained at the end of 2 days. The actual precentage would then be 14.2 per cent, or an average of about 17 per cent. The 40 per cent moisture pots lost about 800 gm. and went to a minimum of about 28 per cent moisture, an average of about 34 per cent being maintained. Records of actual losses were kept, but were not important enough to be given here.

ANALYTICAL METHODS

Nitrate in the soil was determined by the phenoldisulfonic method, as described by Harper (4). Moisture in the petioles was determined by heating 10 gm. to constant weight at 80°C. Nitrate, phosphate, and potash in the plant were determined as previously described in other papers (1, 2, 3).

The samples for the determinations on the plant were taken from the large part of the petioles of the lower mature leaves, next to the main stem. Uniform samples were possible here, and the nearest approach to the actual nutrients flowing through the main stem could be had without destroying the plant. The last determination was made on the main stem, at the conclusion of the experiment.

PRESENTATION AND DISCUSSION OF RESULTS

Effect on growth characteristics of the plant

Table 1 shows the relative height, color, and green weight of the plants at the different amounts of moisture.

The 10 per cent soil moisture resulted in a dark green, woody, stunted plant. The dark green color evidently was due to a concentration of nitrate at the expense of further growth. The 20 per cent soil moisture resulted in medium succulence and good growth with a medium green appearance. The plants always looked healthy.

The 40 per cent soil moisture resulted in a very large, succulent vegetative growth. The plants were a lighter green color than with the 20 per cent mois-

ture. In several an unnatural yellowish color began to predominate toward the end of the experiment.

No conclusions could be drawn as to fruitfulness, since the volume of soil was not sufficient to carry the plants to normal maturity. Table 1 shows the green weight on the 40 per cent moisture pots to be about twice that on the 20 per cent pots, and four times that on the 10 per cent pots.

TABLE 1

Growth characteristics of plants

SERIES	SOIL MOISTURE*	SOIL	HEIGHT	COLOR OF FOLIAGE	GREEN WEIGHT
	per cent		*inches*		*gm.*
3	10	Station	34	Dark green	105
20	10	Station	36	Dark green	80
31	10	Station + compost	26	Dark green	65
45	10	Station + compost	29.5	Dark green	160
11	20	Station	46.5	Medium	240
21	20	Station	54	Fairly dark green	205
36	20	Station + compost	42	Medium	260
50	20	Station + compost	50	Medium	300
16	40	Station	62	Very pale green	200
25	40	Station	60	Medium	450
40	40	Station + compost	58	Light green	585
52	40	Station + compost	58.5	Light green	510

* The percentage of moisture is approximate.

Effect on moisture in the plant

The effect of soil moisture on that in the plant is shown in table 2. The plants in soil with 10 per cent moisture contained less water than those in soil with 20 per cent, except pot 11, and these, in turn, less than those in soil with 40 per cent. Evidently the plant endeavored, despite the low soil moisture, to maintain a normal moisture content, resulting in a stunted growth to counterbalance the small amount of moisture. The low moisture evidently hindered photosynthesis and consequently the supply of carbohydrates, resulting in little new tissue formation and an increase in nitrate concentration, due to a lack of its utilization.

Nitrate in the soil

Table 3 shows that the dry soil contained the largest amount of nitrate at the end of the experiment. The amounts of nitrate remaining in the 20 per cent and 40 per cent moisture pots were almost the same, the wettest soil having slightly more, with the station soil but slightly less when compost was added. This shows that the plant is able to take out nitrate to about the same

TABLE 2

Moisture content of plants

SERIES	SOIL MOISTURE*	SOIL	MOISTURE IN PLANT
	per cent		*per cent*
3	10	Station	90.8
20	10	Station	90.6
31	10	Station + compost	91.8
45	10	Station + compost	91.4
11	20	Station	90.7
21	20	Station	91.1
36	20	Station + compost	92.3
50	20	Station + compost	92.1
16	40	Station	93.5
25	40	Station	92.8
40	40	Station + compost	92.7
52	40	Station + compost	92.4

* The percentage of moisture is approximate.

TABLE 3

Nitrate nitrogen in soil

P.p.m. of dry soil

SERIES	SOIL MOISTURE*	SOIL	NITRATE N† FINAL
	per cent		*p.p.m.*
3	10	Station	25.6
20	10	Station	17.3
31	10	Station + compost	24.5
45	10	Station + compost	25.5
11	20	Station	13.4
21	20	Station	13.1
36	20	Station + compost	14.2
50	20	Station + compost	14.7
16	40	Station	14.2
25	40	Station	15.6
40	40	Station + compost	13.7
52	40	Station + compost	13.2

* The percentage of moisture is approximate.

† The initial nitrate in the station soil was 135 p.p.m., and in the composted soil 182 p.p.m.

level, irrespective of the amount of moisture present. It was not taken out of the dry soil because it was not utilized by the plant and became concentrated in the cell sap, which stopped its uptake by the plant.

Effect of soil moisture on nitrate in the plant

Table 4 presents the actual parts per million on the green weight basis of nitrate nitrogen found in the mature conducting tissues of the plant represented by the lower mature petioles of the leaves and by the entire lower stem at the end of the experiment. Logarithmic figures 2 and 3 represent the data of table 4. The values for January 4 used in the graphs are the average of the morning and afternoon determinations.

In the first stages of growth the plants on the 20 per cent moisture soils contained the most nitrate N in all groups but one, where that on the 40 per cent

TABLE 4

Nitrate analysis

P.p.m. of fresh tissue

POT NUMBER	SOIL MOISTURE*	SOIL	NITRATE IN PLANT					AVERAGE NO_3 IN PLANT†
			12/11/31	1/4/32 (a.m.)	1/4/32 (p.m.)	1/11/32	2/2/32	
	per cent		*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
3	10	Station	522	843	781	362	312	564
20	10	Station	558	694	1,190	500	...	729
31	10	Station + compost	906	481	658	500	500	609
45	10	Station + compost	1,035	781	833	500	500	730
11	20	Station	600	347	357	161	26	298
21	20	Station	690	280	609	161	...	435
36	20	Station + compost	1,021	624	641	274	62	524
50	20	Station + compost	1,208	694	694	454	34	617
16	40	Station	290	136	125	71	20	128
25	40	Station	763	448	675	125	...	503
40	40	Station + compost	906	367	581	147	25	405
52	40	Station + compost	906	347	347	109	24	347

* The percentage of moisture is approximate.

† The original nitrate in the plant was determined on a plant of the same size, age, and treatment as those used in the experiment. It was found to be 703 p.p.m. of fresh tissue. This figure was used in obtaining the average nitrate figures.

soil was highest (pot 25). Evidently nitrification was most rapid in the soil with 20 per cent moisture and the plant absorbed more. Soon, however, the stunting of plant growth on the 10 per cent moisture pots caused a lack of nitrate utilization, and nitrate accumulated, causing a dark green color and high nitrate level, as shown in the graphs. The plants in the 40 per cent moisture pot showed the lowest percentage of nitrate at nearly all times, showing either that nitrification was not so rapid in the wet as in the medium wet soil or that nitrate was utilized more rapidly by the plant in new tissue formation. The small increase in succulency and moisture in the plant could hardly account for

the decreased nitrate concentration. The graphs also show that nitrate concentrations become lower as the plant matures, although the stunted plants in the 10 per cent moisture pots maintained high nitrate levels to the end, as compared with the normal plants.

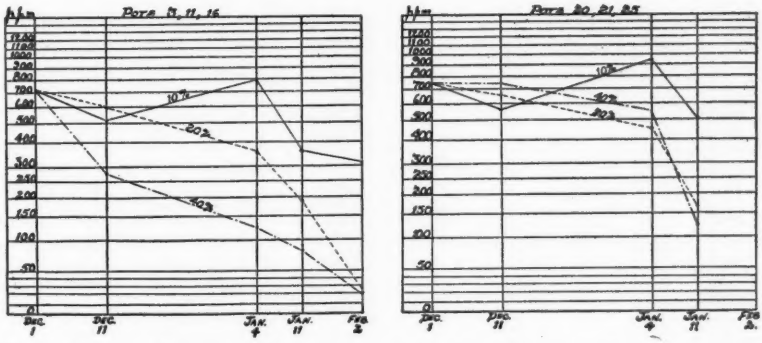


FIG. 2. NITRATE NITROGEN IN MATURE TOMATO PETIOLES GROWN IN SOILS CONTAINING 10, 20, AND 40 PER CENT MOISTURE
(Station soil)

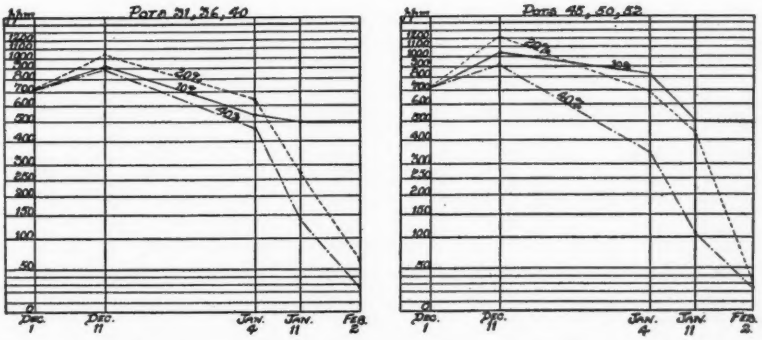


FIG. 3. NITRATE NITROGEN IN MATURE TOMATO PETIOLES GROWN IN SOILS CONTAINING 10, 20, AND 40 PER CENT MOISTURE
(Three-fourths station soil, one-fourth compost)

Effect of soil moisture on phosphate in the plant

Logarithmic figures 4 and 5 represent the data on phosphate found in the same sample taken for nitrate. The plants on the dry soil showed a little the most phosphate at first but as the readily available phosphorus was used the phosphate dropped until at the end of the experiment the curves in all four cases showed that a lack of moisture had a decidedly depressing effect on the

phosphate concentration in the plant. It will be noted that the 40 per cent moisture caused decidedly the highest concentration of phosphate, the 20 per cent moisture caused a medium amount, and 10 per cent decidedly the lowest amount in all four replications. The phosphate, contrary to the nitrate, increased toward maturity in all except the 10 per cent moisture pots. Evidently

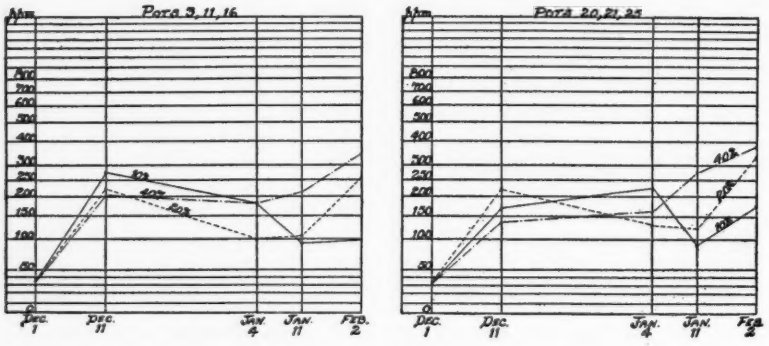


FIG. 4. PHOSPHATE IN MATURE TOMATO PETIOLES GROWN IN SOILS CONTAINING 10, 20, AND 40 PER CENT MOISTURE
(Station soil)

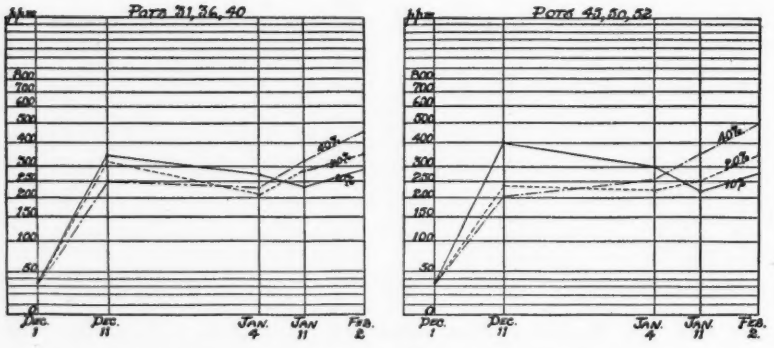


FIG. 5. PHOSPHATE IN MATURE TOMATO PETIOLES GROWN IN SOILS CONTAINING 10, 20, AND 40 PER CENT MOISTURE
(Three-fourths station soil, one-fourth compost)

the roots send up larger amounts of phosphorus when fruits are being set and matured. It seems probable that the lack of phosphate in the plant on the dry soil may be at least partially responsible for the accumulation of nitrate in these plants as previously noted. The lack of moisture also likely reduced carbohydrate formation and further reduced nitrate utilization.

TABLE 5

Phosphate analysis

P.p.m. of fresh tissue

POT NUMBER	SOIL MOISTURE*	SOIL	PHOSPHATE IN PLANT					AVERAGE PO_4 IN PLANT†
			12/11/31	1/4/32 (a.m.)	1/4/32 (p.m.)	1/11/32	2/2/32	
	per cent		*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
3	10	Station	282	217	154	97	100	170
20	10	Station	168	277	166	97	173	176
31	10	Station + compost	331	294	235	232	298	278
45	10	Station + compost	403	333	266	229	266	299
11	20	Station	223	106	91	105	255	156
21	20	Station	226	166	87	126	323	186
36	20	Station + compost	328	208	200	286	344	273
50	20	Station + compost	238	250	174	250	333	249
16	40	Station	216	151	222	216	342	229
25	40	Station	146	200	125	258	370	220
40	40	Station + compost	251	263	190	320	482	301
52	40	Station + compost	206	294	210	345	500	311

* The percentage of moisture is approximate.

† The initial phosphate in the plant was secured on the same sample as used for nitrate. It was found to be 35 p.p.m. This figure was used in securing the average phosphate.

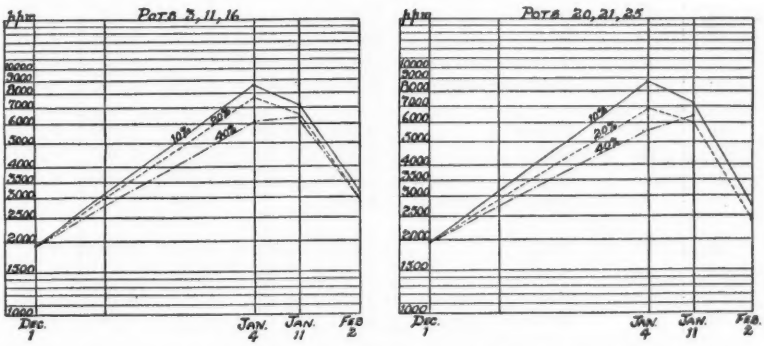


FIG. 6. POTASSIUM IN MATURE TOMATO PETIOLES GROWN IN SOILS CONTAINING 10, 20, AND 40 PER CENT MOISTURE

(Station soil)

Effect of soil moisture on potassium in the plant

Logarithmic figures 6 and 7 present graphically the results on potassium found in the same samples as used for nitrate and phosphate. Table 6 gives a tabulation of the actual parts per million of potassium in the fresh tissue.

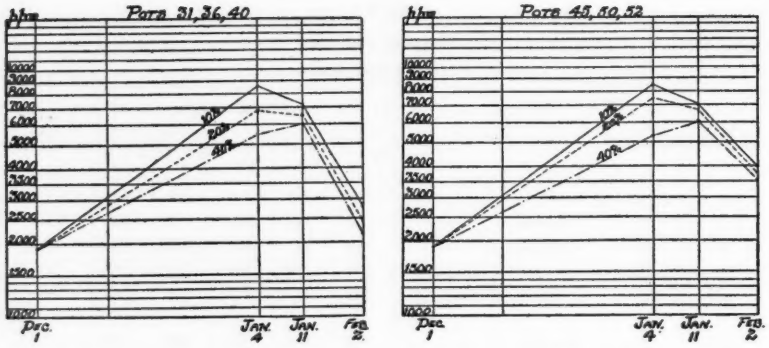


FIG. 7. POTASSIUM IN MATURE TOMATO PETIOLES GROWN IN SOILS CONTAINING 10, 20, AND 40 PER CENT MOISTURE

(Three-fourths station soil, one-fourth compost)

TABLE 6

Potassium analysis

P.p.m. of fresh tissue

POT NUMBER	SOIL MOISTURE*	SOIL	POTASSIUM IN PLANT				AVERAGE K IN PLANT†
			1/4/32 (a.m.)	1/4/32 (p.m.)	1/11/32	2/2/32	
	per cent		*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
3	10	Station	10,709	.....	7,111	3,250	5,396
20	10	Station	10,577	7,157	7,111	2,730	5,572
31	10	Station + compost	10,416	7,058	7,059	2,730	5,903
45	10	Station + compost	10,416	7,058	7,000	3,778	6,183
11	20	Station	8,928	6,666	6,857	3,000	5,144
21	20	Station	7,500	6,476	6,000	2,400	4,509
36	20	Station + compost	7,454	6,476	6,608	2,400	4,877
50	20	Station + compost	8,189	.....	6,800	3,636	4,817
16	40	Station	6,250	5,808	6,545	3,050	4,425
25	40	Station	5,357	5,866	6,476	.....	4,434
40	40	Station + compost	5,147	6,181	6,117	2,235	3,965
52	40	Station + compost	5,147	.....	6,000	3.652	3,755

* The percentage of moisture is approximate.

† The initial potassium in the plant was determined on the same sample as the nitrate. This was found to be 1,939 p.p.m. This figure was used in obtaining the average potassium.

The graphs are almost identical for the four replications. The concentration on the 10 per cent moisture pots was always highest, the 20 per cent moisture pots always medium, and the 40 per cent moisture pots always the lowest. The concentration of potassium rose to a peak and then fell off, probably as the fruits utilized it.

Evidently, lack of moisture did not retard potassium absorption. Since the concentrations did not vary greatly from one moisture percentage to another the fact that the concentration of soluble potassium undoubtedly was greater in the soil solution of the drier soils may have caused the increased concentration in the plants on these soils. The greater succulency of plants on the 40 per cent moisture pots may have caused a sufficient dilution of the cell sap to be partly responsible for the lessened potassium concentration in these plants.

SUMMARY

Soils were adjusted to approximately 10, 20, and 40 per cent moisture and tomatoes grown in them. The moisture was maintained and distributed through the soil by special apparatus and methods. Results are as follows:

Dry soil caused woodiness and a general stunting, with a dark green color.

Succulence increased, and deep green color decreased with increase of water in the soil.

Green weight was proportional to the amount of water.

Moisture in the plant varied with the moisture in the soil, although the differences were small.

More nitrate remained in the soils containing 10 per cent moisture than in the wetter soils. In all soils with 20 and 40 per cent moisture the nitrate was reduced to about the same level.

Twenty per cent soil moisture caused the highest nitrate concentration in the plant at the start and at nearly all times caused a greater concentration than did the 40 per cent moisture. The lower concentration in the 40 per cent moisture tests was likely due either to lessened nitrification in the soil with high moisture, or to more rapid utilization by the plant.

Ten per cent moisture soon caused an accumulation of nitrate in the plant resulting in an abnormally high nitrate concentration soon after the soil was adjusted to 10 per cent moisture. This abnormally high concentration was maintained until the end of the experiment.

Phosphate concentration in the plant varied directly with the percentage of soil moisture after the initial readily available supply was exhausted. Therefore, moisture supply directly influenced the availability of phosphate phosphorus.

The wetter soils maintained somewhat lower concentrations of potassium. This was likely due to the diluting effect and succulency of the tissue. The availability of potassium apparently was not favored by the presence of a large amount of soil moisture.

It seems that the major effects of low soil moisture are: (*a*) lessened nitrification in the soil but not lessened ability to absorb nitrate by the plant; (*b*) lessened ability of the plant to absorb phosphate and consequent nitrate accumulation in the tissue because of retarded tissue formation; and (*c*) a decreased water content in the plant which probably limits both photosynthesis and general metabolic processes in the plant.

REFERENCES

(1) EMMERT, E. M. 1929 The determination of nitrate in green tomato and lettuce tissues. *Plant Physiol.* 4: 519–528.

(2) EMMERT, E. M. 1930 A method for the rapid determination of phosphate in fresh plant tissues. *Plant Physiol.* 5: 413–417.

(3) EMMERT, E. M. 1931 A rapid colorimetric method for the determination of potassium by the use of cobaltinitrite. *Jour. Assoc. Off. Agr. Chem.* 14: 573–575.

(4) HARPER, H. J. 1924 The accurate detemination of nitrates in soils. *Jour. Indus. and Engin. Chem.* 16: 180–183.

(5) HENDRICKSON, A. H., AND VEIHMEYER, F. J. 1929 Irrigation experiments with peaches in California. Calif. Agr. Exp. Sta. Bul. 479.
(6) MOSIER, J. G., AND GUSTAFSON, A. F. 1917 Soil Physics and Management, p. 196. J. B. Lippincott Co. New York.

THE FOREST FLOOR UNDER STANDS OF ASPEN AND PAPER BIRCH

F. J. ALWAY AND JOSEPH KITTREDGE, JR.

University of Minnesota and Lake States Forest Experiment Station

Received for publication September 13, 1932

The most widespread type of forest in the Great Lakes region is the aspen, often somewhat mixed with the paper birch.[1] In connection with a project of the Lake States Forest Experiment Station on the possibilities of converting aspen-birch stands to more valuable tree species, samples of the forest floor were collected in 1925 from nine plots, on each of which detailed measurements of the forest stand were made and the volatile matter, nitrogen, lime, acidity, and moisture equivalent determined.

The first three samples are from adjacent permanent sample plots in the Chippewa National Forest near Cass Lake, Minnesota, where conditions were assumed to be uniform, and sample 4 is from a plot 6 miles to the south. The other plots are more widely separated (table 1), those at Bagley lying 40 miles to the west of Cass Lake, those at Ely and Gunflint 130 and 190 miles, respectively, to the northeast, and the one at Trout Lake, Wisconsin, 260 miles southeast. The latter three are within the area of Early Wisconsin and the others within that of the Late Wisconsin drift.

METHODS OF SAMPLING AND ANALYSIS

Each sample of the forest floor was from one square foot. This was measured out, cut around with a knife, and the material completely removed down to the mineral soil. In order to compute the amount of dry matter per unit area the whole sample was air dried and kept so until dried at the laboratory at 100°C. and weighed. It proved difficult to make an entirely satisfactory separation but extreme care was taken in all cases. All samples except sample 2, were taken of the surface 6 inches of mineral soil thus exposed. Nitrogen was determined by the Kjeldahl method, volatile matter by prolonged ignition at dull redness, and lime by extracting the ash resulting from this ignition with *aqua regia* and precipitating as calcium oxalate. The acidity was determined by the Truog method and the hydrogen-ion concentration by the gas chain electrometric method with a bubbling hydrogen electrode and constant mechanical shaker. The moisture equivalent was determined by the usual method, at 1,000 times gravity. On the samples of mineral soil the determina-

[1] Kittredge, J., and Gevorkiantz, S. R. 1929 Forest possibilities of aspen lands in the Lake States. Univ. of Minn., Agr. Exp. Sta. Tech. Bul. 60.

TABLE 1

Sources of samples and character of soil

SAMPLE NUMBER	LOCALITY	SECTION	TOWNSHIP NORTH	RANGE	SOIL
1	Cass Lake, Minn.	6	144	30 West	Fine sand
2	Cass Lake, Minn.	6	144	30 West	Fine sand
3	Cass Lake, Minn.	6	144	30 West	Fine sand
4	Cass Lake, Minn.	6	143	30 West	Fine sand
5	Ely, Minn.	8	63	12 West	Loamy sand
6	Gunflint, Minn.	9	64	1 West	Loam
7	Bagley, Minn.	24	147	38 West	Fine sand
8	Bagley, Minn.	22	147	38 West	Fine sand
9	Trout Lake, Wis.	32	52	6 East	Loamy sand

TABLE 2

Properties and composition of the forest floor

Sample numbers are arranged in order of basal area

SAMPLE 2	SAMPLE 1	SAMPLE 6	SAMPLE 7	SAMPLE 8	SAMPLE 3	SAMPLE 5	SAMPLE 9	SAMPLE 4	MAXIMUM	MINIMUM
Age of trees in years										
38	38	40	30	40	38	41	19	30	41	19
Basal area, per acre in square feet										
111.9	110.3	106.3	105.8	103.8	93.8	91.5	86.1	51.9	111.9	51.9
Crown density										
0.6	0.6	0.7	0.8	0.9	0.7	0.5	0.8	0.3	0.9	0.3
Weight per acre of oven-dry forest floor, in pounds										
43,000	37,960	25,050	29,600	36,200	42,300	27,000	39,800	8,340	43,000	8,340
Organic matter (volatile matter) per cent										
45.2	64.7	56.2	65.7	69.1	52.9	56.5	44.3	46.9	69.1	44.3
Weight per acre of organic matter, in pounds										
19,436	24,560	14,078	19,447	25,014	22,377	15,255	17,631	3,911	25,014	3,911
Nitrogen in dry material, per cent										
0.87	1.49	1.22	1.63	1.63	1.14	1.16	0.91	1.20	1.63	0.87
Nitrogen in organic matter										
1.93	2.30	2.17	2.48	2.36	2.15	2.05	2.05	2.56	2.56	1.93

TABLE 2—*Concluded*

SAMPLE 2	SAMPLE 1	SAMPLE 6	SAMPLE 7	SAMPLE 8	SAMPLE 3	SAMPLE 5	SAMPLE 9	SAMPLE 4	MAXIMUM	MINIMUM
Nitrogen per acre, in pounds										
374	565	306	482	590	482	313	362	100	590	100
Nitrogen in surface 6 inches of soil, per cent										
.....	0.08	0.11	0.06	0.09	0.19	0.07	0.07	0.05	0.05	0.19
Lime in oven-dry material, per cent										
1.73	2.94	2.42	4.02	4.01	1.79	1.75	1.45	2.25	4.02	1.45
Lime computed to organic matter, per cent										
3.83	4.54	4.31	6.12	5.80	3.38	3.10	3.27	4.80	6.12	3.10
Lime per acre, in pounds										
744	1,116	606	1,190	1,452	757	472	578	188	1,452	188
Moisture equivalent										
84	144	105	116	127	82	105	112	84	144	82
Acidity, by Truog method										
Medium	Slight	Very slight	Very slight	Very slight	Medium	Slight	Medium	Very slight	Medium	Very slight
Acidity of underlying 6 inches of soil, by Truog method										
.....	Medium	.....	Slight	Slight	.....	Strong	Very strong	Medium	Very strong	Slight
pH value										
5.6	5.8	5.7	6.3	6.4	5.4	5.6	5.2	5.9	6.4	5.2
pH value of underlying 6 inches of soil										
.....	4.4	.....	5.4	5.4	.....	4.7	4.4	4.9	5.4	4.4
H-ion concentration ($C_H \times 10^{-7}$)										
25	16	20	5	4	40	25	63	12	63	4
H-ion concentration of underlying soil										
.....	400	.....	40	40	.....	200	400	125	400	40

tions were limited to nitrogen, acidity, hydrogen-ion concentration, and moisture equivalent. The results are given in table 2.

AMOUNT AND CHARACTER OF FOREST FLOOR

Amount

The amount per acre varied from 8,340 pounds of oven-dry material in sample 4 to a maximum of 43,000 pounds in sample 2, both from near Cass Lake but taken 6 miles apart. In samples 1 and 2, taken adjacent to the latter, the amounts were very similar, viz. 37,960 and 42,300 pounds.

Volatile matter

The volatile matter in the oven-dried samples varied from 44.3 per cent in sample 9, from Trout Lake, to 69.1 per cent in sample 8, from Bagley. Almost as wide extremes are shown by two adjacent plots at Cass Lake, samples 1 and 2, in which the percentages of volatile matter were 64.7 and 45.2, respectively. The weight of volatile matter per acre varied from 3,911 pounds in sample 4 to 25,014 pounds in sample 8.

Nitrogen

The nitrogen in the oven-dry samples varied from 0.87 per cent in sample 2 to 1.63 in samples 7 and 8. Here also the samples from adjacent plots, samples 1 and 2, show almost the extremes, viz. 1.49 and 0.87 per cent.

Nitrogen in volatile matter

When the nitrogen is computed on the basis of the volatile matter the range is less, being only from 1.93 to 2.56 per cent, with 2.30 per cent in sample 1 and 1.93 in sample 2. The amount of nitrogen in the forest floor per acre varied from 100 pounds in sample 4 to 590 pounds in sample 8.

Lime

The lime content of the dry material varied from 1.45 per cent on sample 9, from Trout Lake, to 4.01 and 4.02 in samples 7 and 8, from Bagley, whereas on the basis of the volatile matter the range was from 3.10 to 6.12 per cent. All are far above the minimum values found for peats that are well enough supplied with lime for the most calciphile cultivated crops.[2]

Moisture equivalent

The moisture equivalents, unlike the chemical values and acidity, were determined on the unground but well-mixed samples. They varied from 82 to 144, the extremes being found on the group of adjacent plots at Cass Lake.

Acidity and hydrogen-ion concentration

The determinations by the Truog method showed only very slight to medium acidity, whereas the electrometric determinations gave pH values of 5.2 to 6.4,

[2] Alway, F. J. and Nygard, I. J. 1927 Differentiation between lime deficiency and acidity in the case of peat soils. *Proc. First Internatl. Cong. Soil Sci.*, 2: 22–44.

or $C_H \times 10^{-7}$ values of 4 to 63. Thus none of the samples showed any decidedly acid condition. The surface of the underlying mineral soil was in all cases decidedly more acid, with a hydrogen-ion concentration in general about 10 times as great as that of the overlying forest floor, the $C_H \times 10^{-7}$ values of the six samples examined showing a range from 40 to 400.

DISCUSSION

The comparatively slight variations in the properties of the nine samples of forest floor make positive conclusions difficult other than the uniformly high content of lime and moderate content of nitrogen in the volatile matter (table 3). Sample 4, from the stand which had the lowest basal area and the lowest crown density, had much the lowest weight per acre of forest floor—only one-

TABLE 3

Properties of the forest floor samples arranged in order of lime content of the organic matter, assuming that all of the lime is combined with this

SAMPLE NUMBER	CaO WITH VOLATILE MATTER	REACTION	VOLATILE MATTER	N IN VOLATILE MATTER	NITROGEN IN SAMPLE	LIME IN SAMPLE	MOISTURE EQUIVALENT
	per cent	*pH*	*per cent*	*per cent*	*per cent*	*per cent*	
7	6.12	6.3	66	2.48	1.63	4.02	116
8	5.80	6.4	69	2.36	1.63	4.01	127
4	4.80	5.9	47	2.56	1.20	2.25	84
1	4.54	5.8	65	2.30	1.49	2.94	144
6	4.31	5.7	56	2.17	1.22	2.42	105
2	3.83	5.6	45	1.93	0.87	1.73	84
3	3.38	5.4	53	2.15	1.14	1.79	82
9	3.27	5.2	44	2.05	0.91	1.45	112
5	3.10	5.6	56	2.05	1.16	1.75	105

third as much as the next highest, sample 6. The former plot had been burned over after the aspen started, 30 years before, which may account for the small accumulation of forest floor. On plot 65, at Bagley, also with 30-year-old trees, the amount of forest floor was three times as great. Low basal area and low age, at least down to 20 years, do not appear to result necessarily in low amounts of floor per unit area, as evidenced by a comparison of sample area 8 at Bagley with number 9 at Trout Lake. On the latter the amount of floor is a little the higher although the trees are scarcely half as old and have only four-fifths as great a basal area.

The properties, other than weight per acre, show no constant relation to age, basal area, or crown density of the forest cover. The lack of relationship is not only evident in general but also specifically on the three adjacent and similar Cass Lake plots, on which the floor varied in properties almost as much as between the most widely separated areas, as for example in the moisture equivalents and the percentages of volatile matter and nitrogen. The causes of the differences apparently are not to be found in the age or density of the forest

cover. Samples 5 and 9 from the area of the Early Wisconsin drift have lower percentages of lime than the others, all of which are from the very calcareous Keewatin drift, a fact which suggests a relation to the mineral soil underlying the forest floor.

SUMMARY

Under stands of aspen-paper birch, the most widespread type of forest in the Great Lakes region, the forest floor was sampled in nine places. The amount per acre varied from 4 to 21 tons, the content of volatile matter from 44 to 69 per cent, and that of nitrogen from 0.87 to 1.63 per cent, corresponding to 2 to 12 tons of volatile matter and 100 to 590 pounds of nitrogen per acre. The percentage of nitrogen in the volatile matter varied from 1.93 to 2.56. The pH values ranged from 5.2 to 6.4 and the moisture equivalent from 82 to 144.

SOIL PROFILE STUDIES: V. MATURE PODZOLS

J. S. JOFFE AND C. W. WATSON

New Jersey Agricultural Experiment Station[1]

Received for publication August 20, 1932

One of the distinctive morphological features of a mature podzol is the bleached horizon A_2. The origin and mode of formation of this horizon have been discussed in an earlier publication (2). Within the podzol zone not all of the soils exhibit a morphologically distinguishable A_2 horizon. Some of them show chemical evidence of podzolization only, as shown elsewhere (3). A more clear-cut picture of a podzol, its chemical, physical, and even biological characters is, however, to be drawn from a podzol soil which has a definitely developed, morphologically distinguishable A_2 horizon. Such podzols are to be found on the Lakewood and sometimes the Collington and even on the Sassafras series of soils in New Jersey. A description and analysis of two podzol profiles of the Lakewood series is the subject of this paper.

PROFILE 1

Geographic position of area. The area where the samples from profile 1 were taken is located between the parallels 40° 16′ and 40° 14′ north latitude and between the meridians 74° 08′ and 74° 06′ longitude, south of the Hockhockson Swamp. The profile cut was made near the road which leads southeast to Green Grove. The region where this area is located is known as the Freehold area in the soil survey of New Jersey.

Topography, geological, and climatic features. The topography is level with slight undulations, and the area under consideration is on the more elevated level which dips gently to the east and to the streams which feed the Hockhockson Swamp to the northwest.

Geologically the area is in the Coastal Plain Province, which consists of formations of unconsolidated almost horizontal beds of gravel, sand, sandy clay, and marls with a slight dip to the coast. These formations are chiefly Tertiary, the upper Miocene.

The climate of the region is characterized by the relatively narrow daily and monthly ranges of temperature. The rainfall is rather heavy, averaging about 50 inches annually, with a minimum of about 40 and a maximum of over 70 inches. The mean annual temperature is about 53°F. with an absolute minimum of −11°F. and an absolute maximum a little over 100°F. During

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and bacteriology.

the winter the ground freezes a few inches deep, but it does not remain in that condition all through the winter. Frequent thawing out takes place during the winter. The humidity is relatively high, except during some periods during the fall. An important feature of the rainfall element of the climate is its relatively even distribution. All of the climatic factors are therefore conducive to a thorough leaching of the soil, which in turn is effective as far as the process of podzolization is concerned.

Vegetation. The area is covered in places with pure stands of pitch pine (*Pinus rigida*), in all probability not the original timber. In places there is a mixed stand of pitch pine with black and white oak. An abundance of blueberry bushes (*Vaccinium*) is very characteristic of the area.

Description of soil profile

Ao: practically none, except for superficial debris of undecomposed leaves and twigs.

A_1: 13 cm. deep. Sandy material intermingled with some decomposed organic matter, light in color, structureless.

A_2: 25 cm. Bleached white sand, very distinct line of demarcation between the overlying A_1 and underlying B_1 horizons. In places it goes down into B_1 in pocket-like formation. No structure is apparent; it is slightly smeary when wet, dusty-like when dry. No visible traces of organic matter.

B_1: 20 cm. Light brown sandy material with tongues and pockets of white sand; it is slightly compacted showing indications of some structure, with a slightly heavier texture than A.

B_2: 35 cm. Light brown sandy material with darker (iron and humus) concretions scattered throughout. There are definite signs of a crumbly to a nutty structure with no indications of lamination. Like B_1 it is more compact than A_1 or A_2 with a slightly heavier texture than A.

C: A light brown fine sand, unconsolidated, with specks of mica scattered throughout, going down several feet deep.

It is clear that morphologically we are dealing with a genuine podzol of a mature age. And, of course, the chemical analyses show that the distribution of the chemical constituents in the profile is true to form for the podzolization process.

Ao layer. It is of interest to note that on the more elevated (microrelief features) spots of the area the Ao layer is feebly developed and in places there is practically none. This has been noted to be especially true in the pure stands of pine (usually pitch), but it has also been found to be true even in areas with a mixed stand of pine and oak (black and white). There is only a superficial cover of undecomposed and partly decomposed forest debris without the formation of a well-defined mat. Such observations have been made also with Dr. C. F. Marbut, whom the senior author had the opportunity to accompany during the summer of 1931, while he was studying the Freehold area and checking up some points with reference to the survey which was made earlier by Lee

and Tine (7). In his write-up, Marbut (7) refers to the peculiar condition of the Ao layer.

In connection with the process of formation of an Ao in the section under investigation, the frequent forest fires have to be considered. In the open areas the forest floor becomes thoroughly dry and is easily burned. This, of course, prevents the accumulation of organic matter. On careful examination one may find in the Ao-free area small depressions, in the more shady spots, a well-formed mat of organic matter. The damp conditions in these localized areas apparently protect the organic matter layer from the ravages of fires.

Chemical characteristics of profile 1

In table 1 the total analyses of the soil material in the respective horizons of the profile are presented.

SiO_2. True to form the A_2 horizon is highest in SiO_2, with a sharp decrease in the B horizon and an increase again in the C horizon. The data indicate a

TABLE 1

Total chemical analyses of soil profile 1 (mineral constituents)

LABORATORY NUMBER	HORIZON	DEPTH OF HORIZON	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O
		cm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
78	A_1	13	97.16	1.3	0.407	0.118	0.0723	0.225
79	A_2	25	98.12	1.1	0.315	0.121	0.0795	0.200
80	B_1	20	93.32	1.9	2.50	0.124	0.1122	0.340
81	B_2	35	93.40	1.9	2.65	0.143	0.1157	0.365
82	C	..	95.97	1.35	2.09	0.203	0.1447	0.415

disruption of the silicate complex in the horizon of eluviation with the consequent loss of bases, splitting off of the sesquioxides, and separation of SiO_2. Hence an increase of SiO_2 in the horizon of eluviation, especially in A_2. The lower increase of SiO_2 in A_1 is apparent only since A, has a high organic matter content, in comparison with A_2, which is added to the mineral material from outside sources—the atmosphere and hydrosphere. There is, however, another important point to consider, namely, the fact that the disruption of the silicate complexes in A_1 is somewhat hindered because of the enrichment with Ca which comes from the mineralization of the organic matter increasing thereby the pH. True, the Ca remains there only temporarily, but it is apparently effective in preserving some of the silicate complexes. More evidence to that effect will be brought out in the discussion of the R_2O_3 data.

Not all of the SiO_2 released in the horizon of eluviation remains there. Some of it moves downward, as evidenced by the morphological features: tongue shaped protrusions and spots of bleached material in the B horizon. Thus the increase of SiO_2 in A_2 is not absolute but relative. The losses of bases and R_2O_3 exceed the loss of the SiO_2, and hence there is an apparent increase of SiO_2.

As we come to analyze the decrease of SiO_2 content in the B horizon, we must recognize again that it is only apparent, i.e., there is no actual loss of this constituent from the B horizon. The illuviation process brings about an increase of bases, sesquioxides, and various colloidal materials. These naturally decrease (relatively) the percentage of the total SiO_2 in the B horizon.

The increase of the SiO_2 content in the C horizon, as compared with B, is also only apparent. Since the parent material of this soil is geologically a transported material, the weathering forces as such were subdued at the time the soil forming processes came into play. Parent material from a geologically residual rock material is very strongly subject to the action of the forces of weathering, simultaneously with the forces of the soil forming processes. It is therefore logical to conclude that in the case under consideration the parent material has not undergone any very marked transformations ever since the soil forming processes set in.

Iron and aluminum. Mention has been made elsewhere (5) that in the circulation of the elements through the profile the sesquioxides are among those which do not return in any appreciable quantities as the bases do. Plants take up very little Fe and still less, if any, Al. As a result, one would expect a low sesquioxide content in the horizon of eluviation and an accumulation of these sesquioxides in the horizon of illuviation. This should be more true for the Al than for the Fe for two reasons. First of all, practically none of the Al is returned to the Ao layer through the plants. Secondly, the Al moves faster than the Fe because of the higher isoelectric point of Al. This has been brought out by the studies of Mattson (11), Joffe and McLean (6), and Joffe (4). The data in table 1 substantiate the statement made in the foregoing: more of the Al than the Fe has disappeared from A_1 and A_2, and relatively more Fe has accumulated in B.

The data on the sesquioxide content of the A_1 and A_2 horizons respectively are interesting. There are more Fe and Al in the A_1 than in the A_2 horizon. If it were the Fe alone one would be prone to ascribe the phenomenon to the return of this element by the organic matter of the accumulative Ao layer. Such an explanation, however, could not be accepted for the Al, which is not returned. It must be sought in the make-up of the silicate complexes and the degree of decomposition of these in the respective horizons, mention of which has been made in the discussion on the distribution of SiO_2 in the profile. The higher sesquioxide content in the A_1 horizon may serve as further evidence of the lower degree of disruption of the silicate complexes in the A_1 as compared with the A_2 horizon. There is also the possibility that the humus complexes in the A_1 tie up some of the sesquioxides.

In the analysis of any podzol the accumulation of the sesquioxides in the B horizon is very significant for a clear understanding of the process of podzolization. The accumulation of the sesquioxides represents the release of these from the horizon of eluviation in the process of humification and mineralization of organic matter and their precipitation in the horizon of illuviation because

of the higher concentration of bases and other electrolytes, which create the proper conditions—pH and other electrokinetic behavior—for the isoelectric state of these constituents.

An important function of the sesquioxides is their cementing action. Together with the fine particles which move downward mechanically they clog up the pore space making the B an impervious horizon. It is the cementing action of the sesquioxides which is responsible for the formation of orterde and ortstein.[2] A contributing factor in the retention of the sesquioxides is the irreversibility of the gels as they age or undergo the effects of drying. In a way the sesquioxides in the B horizon may be looked upon as the agents which prevent the further disintegration and decomposition of the soil materials, which makes this horizon a temporary storehouse of the substances used by the plant roots.

Calcium, magnesium, and potassium. A glance at the figures in table 1 on the distribution of Ca, Mg, and K in the profile shows that these three elements behave somewhat alike. About 50 per cent of each one of them has disappeared from the horizon of eluviation, when we take the percentage composition of the material from the C horizon as a basis for comparison. These three element show a relative increase in B, when compared with A, but not with C.

If we stop to analyze the data on these three elements separately, especially with reference to the B horizon, we may note that each one of them shows a behavior of its own. Thus the Ca shows the lowest accumulation (about 12 per cent when compared with A); Mg, a higher accumulation (about 44 per cent); and K, a still higher accumulation (about 66 per cent).

Two factors contribute to the low accumulation of Ca in B. First of all it enters into circulation through the profile to a greater extent than Mg because of the higher assimilation of Ca by plants. Secondly, the Ca is more readily leached and lost than the Mg, which might form new complexes of an insoluble nature and is apparently held more firmly in the complex.

The rather high K content in B and C is probably due to the presence of some greensand marl. This soil should therefore be classified as Collington following the nomenclature of the Soil Survey. There is not, however, enough of the glauconitic material in the parent material which could readily be recognized, and for that reason probably it has been mapped as Lakewood.

Distribution of organic matter and nitrogen in the profile

C:N ratio. In the soil microbiology literature on the organic matter content of the soil, the opinion prevails that the C:N ratio approaches, within limits, the figure 10. A great many deductions on the microbiological processes in cultivated soils have been made because of this ratio with no consideration to the intimate relationships existing between the horizons in the soil profile.

The data in table 2 reveal a decided variability of the C:N ratio in the profile.

[2] A more detailed discussion of ortstein formation may be found in a former publication (2).

The high ratio in A_1 is probably due to some charcoal which could be found all over the area as a result of the frequent forest fires. One should in general expect a high C:N ratio in this horizon because it is underlying the Ao layer and therefore receives much fresh organic matter, and besides it contains a lot of the fine roots of the herbaceous vegetation. Even though this profile showed but a feebly developed Ao layer, still there was enough to influence the percentage of the total organic matter and, of course, also the C:N ratio.

The C:N ratio in the other horizons is more significant. In A_2 it is lower, because of the high N content in the organic matter. Why there should be a high N content in A_2 will be discussed presently. The ratio goes up again in B_1, drops in B_2, and still more in C, where it approaches the generally accepted C:N ratio. It appears that in the sandy type of podzols the C:N ratio is far above 10.

TABLE 2

Distribution of organic matter and nitrogen in profile 1

LABORATORY NUMBER	HORIZON	DEPTH OF HORIZON	TOTAL C	TOTAL ORGANIC MATTER*	TOTAL N	N IN ORGANIC MATTER†	$\frac{C}{N}$ RATIO
		cm.	*per cent*	*per cent*	*per cent*	*per cent*	
78	A_1	13	0.75	1.303	0.0156	1.11	48.3
79	A_2	25	0.118	0.2034	0.0078	3.79	15.2
80	B_1	20	0.55	0.9482	0.0231	2.41	23.8
81	B_2	35	0.43	0.7413	0.0241	3.21	17.8
82	C	..	0.09	0.1542	0.0085	5.42	10.6

* Total C was multiplied by the factor 1.724.

† It is assumed that all of the N is in the organic matter.

Organic matter and N content. The outstanding feature about the organic matter distribution in the soil profile is the increase of it in the B horizon. Although there is no definite correlation between the R_2O_3 and the organic matter in the different horizons, it is apparent that an increase of one is followed by an increase of the other. This is controlled by the presence of other electrolytes and the pH. Apparently the pH at B is the isoelectric pH for the precipitation of higher amounts of humates. According to Mattson (11) at lower pH values a smaller proportion of R_2O_3 constituents is required for high humus fixation. If the R_2O_3 and humus complexes or a part of them in B are of such nature, then an increase in pH should release some humates. When the soil material was treated with a neutral salt at pH 7.0 for the determination of unsaturation, a release of humus substances took place as discerned by the color.

The R_2O_3 and humus accumulation in the B horizon is conducive to ortstein and orterde formation. Theoretically a higher pH should tend to form an iron ortstein and a low pH, a humus ortstein. More studies on the concretions of Orterde and of ortstein in podzols of various parent materials and pH are wanted to corroborate this.

True to form, horizon C has a very low organic matter content, but its adjacent position with respect to B_2, which has a high organic matter content, is favorable to the reception of some of the highly dispersed organic materials from above. Undoubtedly some of these organic complexes become more soluble at increased pH environments, which occur sometimes during the fall season, as pointed out elsewhere (5). These finely dispersed organic materials are high in nitrogen and, perhaps, this will explain the extremely high N content of the organic matter in horizon C.

As pointed out in the discussion on the $\frac{C}{N}$ ratio, the A_1 is contaminated with charcoal. This, of course, makes the total organic matter content appear somewhat higher than it actually is. It also brings down the percentage of N in the organic matter.

The low organic matter content in A_2 is reasonable in the light of the reactions that take place in this horizon. It is the horizon where most of the destructive or decomposition reactions take place in the process of soil formation. Morphologically one could hardly recognize the organic matter in this horizon. Charring the apparently pure white bleached sand brings out the fact that there is some organic matter and the chemical analyses prove that. However, there is a different type of organic matter in each one of these horizons. This is especially reflected in A_2. The organic matter is colorless and it is probably, as suggested by Williams (12), of the crenic and apocrenic acid type, which, by the way, contain 3 to 4 per cent N. This might explain the high N content in the organic matter of this horizon. It is very likely that the organic matter of this horizon is highly contaminated with fungus mycelium, since the reaction environment in this horizon is unfavorable for bacterial activity and favorable for fungi. It is to be recalled that fungus mycelium contains from 4 to 6 per cent nitrogen.

The high organic matter content in B is accompanied by a high percentage of N, as shown in table 2. The B_2 is higher in N than B_1. As explained in connection with the discussion on organic matter in horizon C, it is the degree of dispersion that controls the N content. The more highly dispersed particles are of a higher N content, and, with an increase in depth of the profile through B, there is an increase in the fineness of the particles. Edington and Adams (1) present results which show an enrichment of N in the B horizon of the podzol which they studied.

The total N content of the podzol soil under consideration follows the trend of the R_2O_3 or of the organic matter: lowest in A_2, increase in B, and a drop in C. The N content of A_1 is comparatively low because of the absence of an Ao layer, which usually increases the total organic matter content, and even though the percentage of N is as a rule low in A_1, its total N is high. In this case the results are obscured by the presence of charcoal, of which mention has been made.

Base exchange and unsaturation of soil

The podzol nature of this profile is very strikingly illustrated by the data in table 3, on the base exchange capacity and unsaturation of the soil in the various horizons. The A_1 horizon shows a rather high exchange capacity as compared with that of A_2 and C. As pointed out elsewhere (3), this is probably due to the relatively high organic matter content in A_1, higher than in any other horizon. Besides that, there seems to be, as pointed out in the discussion on the SiO_2 content, some mineral complexes in A_1, which are not disrupted and which probably manifest some exchange capacity. That most of the exchange capacity must be ascribed to the organic complexes is clear from a comparison of this property in A_1 and C, the latter having the smallest amount of organic matter. Only one-fifth of the exchange capacity in A_1 comprises the exchange capacity of C. The base exchange properties of organic matter had been discussed by McGeorge (9, 10).

TABLE 3

Base exchange and unsaturation in profile 1

LABORATORY NUMBER	HORIZON	DEPTH OF HORIZON	BASE EXCHANGE CAPACITY	UNSATURATION: REPLACEABLE H	UNSATURATION	REACTION	
						H_2O extract	Neutral salt extract†
		cm.	*m.e.**	*m.e.*	*per cent*	*pH*	*pH*
78	A_1	13	3.00	2.0	66.6	4.8	4.4
79	A_2	25	0.77	0.55	71.4	4.8	4.8
80	B_1	20	2.74	2.60	94.8	5.1	5.0
81	B_2	35	2.74	2.55	93.0	5.2	5.0
82	C	..	0.64	0.50	78.1	5.2	5.2

* m.e. = Milligram equivalents per 100 gm. of soil.

† A 1.0 *N* solution of neutral $BaCl_2$ was used.

It is of interest to note the low (as compared with A_2 and B) percentage of unsaturation in A_1: only 66.6 per cent of the base exchange capacity. Apparently some of the Ca, Mg, and K make up the rest of the exchange capacity. And yet its pH is lower than that of the other horizons, except A_2, which is the same as that of A_1.

In A_2 where the most destructive activity of the podzolization process takes place, the exchange capacity drops and the unsaturation increases.

An increase in exchange capacity and unsaturation takes place in B. The origin of the high base exchange capacity is to be sought in the colloidal inorganic complexes which accumulate in this horizon, in the probably new formations—complexes formed by the interaction of the sesquioxides and silica,— and in the organic matter, which is relatively high in this horizon.

A rather peculiar condition to be noted in B is the high unsaturation. It is very probable that this is due to the rapid circulation of the bases. They

seem to be removed rapidly and the H ions take their place. And yet the pH is higher in B than in A, an indication of a true podzol.

PROFILE 2

Geographic position of area. The area is located between the parallels 39° 46′ and 39° 48′ north latitude and between the meridians 74° 22′ and 74° 21′ at the junction of the roads from Cedar Bridge to Manahawken and Tuckerton. It is in the Chatsworth Area of the Soil Survey of New Jersey.

Topography, geological, and climatic features. The topography is generally level and in places hummocky. This localized area is dipping south and west toward the Wading River Valley, which eventually turns eastward—the general direction of the dip. It is about 120 feet above sea level.

The climatic features of the region are very similar to those of profile 1, except for the rainfall, which at the meteorological station in Tuckerton—about 20 miles south of Cedar Grove—is shown to be considerably lower than at Green Grove—the point where profile 1 is located. The mean annual precipitation is 44 inches and 50 inches respectively. The conditions are thus very favorable for the processes of podzolization.

Geologically this area is the same as the one of profile 1 with this difference: the sandy material from which the soil developed is only about 93 cm. deep and is underlaid by a heavy clay. The soil proper up to the C horizon is only 32 cm. deep, whereas in profile 1 the sandy material extends to a depth of several meters and the soil proper up to C is 93 cm. deep.

The vegetation. The area from which the soil sample was taken supports a poorly growing forest of pitch pine (*Pinus rigida*) about 40 years old. There is a dense understory of scrubby black oaks and the herbaceous vegetation is practically one hundred per cent blueberries and huckleberries (*Vaccinium* sp.).

Description of soil profile

Ao: very thin, consisting at best of sparse litter of the last leaf fall of pine and oak. The accumulation of organic debris in partial and advanced stages of decomposition, so characteristic of northern podzols under coniferous forest, is hardly discernible here or is completely absent. There are abundant signs in this region of recurrent forest fires to which may be ascribed the conspicuous dearth of surface organic matter.

A_1: 5 cm. deep. A fine, sandy, structureless material of a blackish gray color, with a considerable amount of incorporated organic matter, chiefly charcoal. The charcoal from forest fires is very evident in coarse particles and is chiefly responsible for the dark color of this horizon.

A_2: 15 cm. deep. A bleached, white sand, loose and structureless, forming a fairly uniform horizontal band in the profile and offering great contrast to the A_1 above and the B_1 below it.

B_1: 5 cm. deep A light brown, sandy horizon of heavier texture than the A horizons and showing more structure than the latter. Sieving showed the pres-

ence of numerous hard concretions of irregular form and from 0.2–1.0 cm. diameter.

B_2: 7 cm. deep. Of a lighter brown color than B_1 and with more concretions than the latter, but of similar structure and texture.

C: 61 cm. deep. A light yellow fine sand of loose structure and lighter texture than the B horizon. It rests upon a heavy clay in this locality.

As a result of the geological formations, as has been indicated, this profile is morphologically identical with profile 1, except for its depth.

Plate 1 is a photographic view of the profile. The clear cut A_2 horizon is typical of the mature podzols in this region. It shows the more pronounced structural constitution of the B horizon and below that the structureless C horizon. The underlying geologic clay formation is clearly shown in the picture.

Chemical characteristics of profile 2

In presenting the data on the chemical characteristics of profile 2, an attempt has been made to emphasize the outstanding differences between profiles 1 and 2, even though both are mature podzols of a very closely related physical, chemical, and morphological natures, and in the nomenclature of the U. S. Soil Survey both are classified as Lakewood sand. It is the finer differences in the make-up of the soil profile that are frequently responsible for certain behavior of the soil, especially its response in terms of vegetation or crops—the ulterior motive of our soil studies.

Table 4 presents the data on the mineral constituents of the soil profile.

SiO_2. Just as in profile 1, the SiO_2 is highest in A_2 with a sharp decrease in B and an increase in C. It is not necessary to repeat the course of the reactions which take place in the processes responsible for the differential distribution of the SiO_2 in the profile. The reader is referred to the discussion of this phase about profile 1. The relatively low SiO_2 content in A_1 is due to the high organic matter content, of which more is to be said presently.

Iron and aluminum. True to form, the horizon of eluviation (A_1 and A_2) is impoverished of the R_2O_3 constituents with an enrichment of the same in the horizon of illuviation (B_1 and B_2).

A distinctive difference, as compared with profile 1, is the higher accumulation of Al_2O_3 in B and the retention, if such were the case, of higher amounts of it in A, *notwithstanding the fact that the total R_2O_3 content in the parent material of these two profiles is not very far apart.* There is more than three times as much Al_2O_3 in the A horizon of profile 2 as in profile 1. Several explanations might be offered to account for this phenomenon. The most plausible one is that the underlying clay formation, to which mention has been made, prevents the rapid carrying off of the sesquioxides. Apparently they lag behind at certain periods and at times are perhaps carried to the upper horizon. This is more true of the Al_2O_3, which has a higher isoelectric pH than the Fe_2O_3, or in other words, it is more mobile. It is probable that the distribution of the Al in this

soil is one of the contributing factors in the unproductiveness of this soil where pitch pine and oak do not attain any considerable size. Further investigations would be necessary before this point could be established.

Calcium and magnesium. The striking feature about the two alkaline earth metals is the very low content as compared with profile 1. Strange enough, it is A_1 where more Ca is found. Undoubtedly this is due to the accumulation of Ca in Ao. The plants apparently gather all the Ca they can find and give it up again to the soil as the litter decomposes. It is very probable that the bases are held temporarily by the residual mineral complexes and also by the organic matter. In general, however, this soil is very low in Ca and this might be another direct and indirect contributing factor in its unproductiveness.

The Mg content is rather high as compared with the Ca content. Probably the parent material of this soil contains some very resistant Mg mineral. This might be inferred from the fact that there is very little translocation of Mg in the profile.

TABLE 4

Total chemical analyses of soil profile 2 (mineral constituents)

LABORATORY NUMBER	HORIZON	DEPTH OF HORIZON	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
		cm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
83	A_1	5.0	90.50	0.72	1.25	0.123	0.119
84	A_2	15.0	97.00	0.69	1.07	0.076	.....
85	B_1	5.0	90.10	1.23	4.02	0.089	0.116
86	B_2	7.0	89.00	1.66	4.65	0.054	0.101
87	C	....	94.10	1.01	2.88	0.056	0.105

Distribution of organic matter and nitrogen in profile 2

C:N ratio. In table 5 the fact that the C:N ratio is far greater than 10—the commonly accepted ratio for cultivated soils—is brought out again. It seems that in this type of podzol (the tendency is probably true for any other mature podzol) such a ratio is typical.

The extremely high ratio in A_1 and A_2 is unquestionably due to the presence of charcoal, which accumulates in this region because of the forest fires. The high ratio in horizon C is difficult to account for.

Organic matter and N content. If we discount the factor of the charcoal in profile 2, the tendency toward accumulation of organic matter in B is also noted in this profile. The same is true if we critically analyze the N content. There is the tendency for a high N content in B, corroborating the analytical results of profile 1.

In general this profile shows a higher total organic matter and N content than profile 1. These follow the increase in R_2O_3 which corroborates the point made in this connection in the discussion of profile 1.

The data on the loss on ignition bring out the fact that, as a rule, this is not a very good index of the organic matter content of the soil.

TABLE 5

Distribution of organic matter and N in soil profile 2

LABORATORY NUMBER	HORIZON	DEPTH OF HORIZON	TOTAL C	TOTAL ORGANIC MATTER*	TOTAL N	N IN ORGANIC MATTER	$\frac{C}{N}$ RATIO	LOSS ON IGNITION
		cm.	*per cent*	*per cent*	*per cent*	*per cent*		*per cent*
83	A_1	5.0	4.22	7.28	0.103	1.41	40.9	7.76
84	A_2	15.0	0.79	1.36	0.009	0.66	87.7	0.71
85	B_1	5.0	1.33	2.29	0.041	1.79	32.4	2.78
86	B_2	7.0	1.21	2.09	0.044	2.10	27.5	3.33
87	C	....	0.27	0.47	0.008	1.70	33.8	0.85

* Total C was multiplied by the factor 1.724.

TABLE 6

Base exchange and unsaturation in profile 2

LABORATORY NUMBER	HORIZON	DEPTH OF HORIZON	BASE EXCHANGE CAPACITY	UNSATURATION: REPLACEABLE H	UNSATURATION	REACTION	
						H_2O extract	Neutral salt extract
		cm.	*m.e.*	*m.e.*	*per cent*	*pH*	*pH*
83	A_1	5.0	11.5	9.55	83.00	4.2	3.4
84	A_2	15.0	1.8	1.05	60.00	4.6	4.2
85	B_1	5.0	7.2	6.50	90.30	4.9	4.6
86	B_2	7.0	6.6	6.30	95.40	5.0	4.8
87	C	....	1.8	1.20	66.60	5.2	5.0

Base exchange and unsaturation of soil

Nothing outstanding is to be inferred from the data in table 6. The reactions of base exchange and unsaturation in this profile are very similar to those of profile 1, and it is superfluous to follow these up again. The higher base exchange capacity and the high total unsaturation in B are easily explained. It is the higher organic matter content which is responsible for this phenomenon. The low pH values obtained by the neutral salt extract method is instructive, inasmuch as it shows the possibility of the hydrolysis effects of the possible Al salts.

Colloid fraction from profile 2

The colloids from the soil material of the various horizons were extracted and subjected to partial analyses with the purpose of establishing some relationships which might illustrate some reactions in the process of podzolization in a typical mature podzol.

The method of preparing the colloid was practically the same as that of the Bureau of Soils. The samples were sieved through a 2-mm. sieve, which allowed to pass almost everything except large woody particles. A 5-kgm. quantity from each horizon was placed into a 3-gallon bottle, 8 liters of distilled water added, and the reaction adjusted to be alkaline to litmus by adding 0.1 *N* NaOH. It was shaken vigorously and then allowed to stand for 24 hours, after which half of the suspension was decanted, water and NaOH added again, shaken, left standing 24 hours, and decanted again. This operation was repeated six times. The decanted suspensions were centrifuged, the colloids precipitated with $CaCl_2$, filtered through Chamberlain "F" filters, washed with H_2O, and dried on a steam bath with a very low flame. The dried material was ground in a mortar for analysis.

Table 7 gives the analyses on the colloid fraction.

SiO_2:R_2O_3. The ratio is highest in the horizon of eluviation and lowest in the horizon of illuviation. This is to be expected. The low pH in A indicates

TABLE 7

Colloid fraction of profile 2

	SiO_2	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{R_2O_3}$	N	C	IGNITION LOSS	ORGANIC MATTER*	$\frac{C}{N}$ RATIO	N IN ORGANIC MATTER	CATION EXCHANGE
	per cent	*per cent*	*per cent*	*molar*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*m.e.*
A_1	74.00	2.23	14.02	8.15	0.720	18.9	37.0	32.60	27.0	2.2	85.4
A_2	79.40	2.06	14.09	8.75	0.259	4.1	44.6	7.10	15.8	3.5	33.6
B_1	45.40	11.69	35.81	1.79	0.456	7.1	23.9	12.24	15.6	3.7	65.4
B_2	43.20	10.84	21.86	2.55	0.362	7.1	23.4	12.24	19.6	3.0	39.0
C	45.60	10.15	21.67	2.76	0.164	1.36	14.6	2.34	8.3	7.0	21.8

* The factor 1.724 was used to calculate the percentage of organic matter.

a destructive acid hydrolysis whereby the sesquioxides are lost and the SiO_2 accumulates, as shown in the columns on the SiO_2, Al_2O_3, and Fe_2O_3 content of the colloids. This is also substantiated by the data on the total analyses of the soil itself in the respective horizons as shown in tables 1 and 4. On the other hand, the accumulation of sesquioxides in the horizon of illuviation (B) tends to decrease the SiO_2:R_2O_3 ratio.

It is questionable, however, whether the increase in the ratio of SiO_2:R_2O_3 in the colloid should be ascribed entirely to the colloidal complex. Undoubtedly some of the SiO_2 is not chemically combined with the sesquioxides as in the complex. There must be a certain limit for the quantity of SiO_2 which makes up the highest SiO_2:R_2O_3 ratio beyond which the SiO_2 is free and inactive. In his studies on the relation of base exchange capacity to the SiO_2:R_2O_3 ratio, Csiky[3] points out that when this ratio passes the value of 7.0, the base exchange capacity begins to drop. This may be offered as further proof that there is

[3] Csiky, J. S. 1932 Base exchange studies. Personal communication from author.

free SiO_2 mixed up with the complex and hence such a high ratio. What apparently happens is that in the process of the decomposition of the clay nuclei SiO_2 is released, but it remains behind in the A horizon. Some of it is in an amorphous form and in the process of colloid extraction it appears with the colloid complex, thereby increasing the $SiO_2:R_2O_3$ ratio.

If we accept the $SiO_2:R_2O_3$ ratio in C as a basis of comparison and remember that only small amounts of amorphous SiO_2 penetrate beyond the B horizon, then the ratios in B_1 and B_2 become significant. The oppositely charged R_2O_3 and SiO_2 colloids released by the forces of the podzol process of soil formation meet at B to become discharged and mutually coagulated giving rise to new formations. The disrupted mineral complexes from A_1 and A_2 because of the same forces attain colloidal dimensions, move downward to be "filtered" out at B. All of that makes the colloid fraction of this horizon more representative, less liable to foreign colloidal intrusions, except perhaps for some free Al_2O_3 and Fe_2O_3, and therefore the $SiO_2:R_2O_3$ ratio is closer to that of the soil colloid fraction. As we compare the ratios of C and B we note that in B it is narrowing. The absence, or rather limited supply, of bases in the soil material and the low pH are conducive to such a medium ratio, becoming narrower as the sesquioxides appear in a medium of a higher base content, or a higher pH.

The low Fe_2O_3 content in A_1 is indicative of the thorough podzolization of the soil under consideration. It is of interest that less Al_2O_3 has disappeared from the colloidal complex in A, as compared with C, than Fe_2O_3. It is probable, as suggested in the discussion on the total analyses of these constituents, that there is some return movement of Al_2O_3 because of the underlying geologic deposits.

Organic matter and N content. The colloid fraction of the organic matter is more instructive than the total organic matter. This is especially true for the A_1 horizon where large amounts of charcoal obscure the true picture of the organic matter in the soil. The method used in dispersing the colloids does not in all probability affect the charcoal, and organic matter content of the colloid fraction is therefore more representative.

The data show that the percentage of N in the organic matter of the colloid fraction is high in A_2. It corroborates the postulate made in the discussion on the organic matter of profile 1 that its nature varies with the horizon in the profile. What makes the C horizon so high in N is difficult to explain, except that the method of dispersion brings into the extract the very fine particles of the organic matter which are as a rule higher in N.

Closely related to the organic matter content is, of course, the C:N ratio. It shows a rather narrow ratio as compared with the C:N ratio on the total soil analyses. The charcoal factor, of course, needs to be considered in this connection. Besides, the method of dispersion does not apparently bring in all of the organic matter. It leaves a residue high in carbon and low in N. Only the fine particles which are higher in N enter into play. The narrower C:N ratio seems to prove this.

There is no close relation between the organic matter and the R_2O_3 in the colloid fraction, as there is in the total soil analysis. Again, this is probably due to the incomplete dispersion of the organic matter.

The data on the loss on ignition do not compare favorably at all with the data on the total organic matter. This discrepancy must be sought in the errors involved in the procedure of "the loss on ignition" rather than in the fact that the factor 1.724 which is used for converting carbon into organic matter may be perhaps too low, especially for the colloids where a high amount of organic matter is found. A discussion on the reliability of this factor has been presented by Lunt (8).

The data on the total N in the colloid fraction show the eluviation condition of A_2, accumulation in B, and a drop again in C. These are characteristic features of the constitution of a mature podzol.

Base exchange capacity of colloid fraction. The data on the base or cation exchange in the colloid fraction show wide variations in the profile, and yet the tendency is for a decrease in A_2 (the high capacity of A_1 is due to the large amount of organic matter), an increase in B, and a decrease again in C. A similar tendency is noted also in the analyses of the total soil.

GENERAL DISCUSSION

The similarity of the two profiles discussed in the preceding pages consists in their maturity, in the clear-cut differentiation of horizons with all the characteristic morphological features of a mature podzol. The chemical analyses corroborate the morphological features. There is, however, one distinctive difference between the two profiles: profile 1 is 93 cm. and profile 2 only 32 cm. deep—figuring the soil body from the surface to the bottom of the B horizon. As pointed out, the shallowness of profile 2 is due to the underlying geologic deposits of clay. Here is a case where the parent material inhibited the growth of the soil body. All other factors being equal, with the exception of the clay deposition where profile 2 developed, the forces of the climate and vegetation produced a deep soil body in one case and a stunted soil body in the other case. From the agronomic point of view the shallow profile means a lesser area of "feeding grounds" for the plants.

In speaking of the maturity of the profiles, it is worth while to take notice of the similarity in composition of B_1 and B_2. It indicates an equilibrium condition with respect to the formation of the horizon of illuviation. The natural course of the growth of this horizon is from the bottom up, and the homogeneity, as far as the chemical composition is concerned, is evidence of the completion of the process.

The maturity of the soil under consideration—the Lakewood series—has been favored by the rapidity and perhaps by the type of decomposition of the forest litter. The fact that large areas of this soil have practically no Ao layer is sufficient proof of the course of decomposition of the organic matter. Another factor contributing to the mature state of this soil is the low Ca content of the parent material, as pointed out earlier in this paper.

The value of total chemical analyses of soil has been repeatedly questioned, especially from the standpoint of soil fertility practices. It must be admitted, however, that from the pedogenic point of view, the total analyses are a great aid in elucidating the reactions which take place in the processes of soil formation. This has been clearly brought out in the presentation of the data on the total analyses of the soils and it has been corroborated by the analyses of the colloid fraction which shed no more light on what is going on in the soil than the total analyses did, except for the important property of the $SiO_2:R_2O_3$ ratio in the colloid fraction, especially in the B horizon. It is probable that by improving the technique of colloid extraction the analyses of the colloid fraction might mean more. As they are, they supplement very effectively the data on the total analyses.

SUMMARY

Data are presented on the morphology and chemical composition of two podzol profiles from the soils of the Lakewood series.

A distinctive morphological feature of the profiles is the practical absence of an Ao layer.

A discussion is presented on the distribution of the mineral constituents SiO_2, R_2O_3, Ca, Mg, and K in the profile.

The importance of the movement of Al_2O_3 and Fe_2O_3 in the profile is pointed out. It is to be noted that some of the R_2O_3 constituents present in the A horizon indicate a slowing down of the decomposition of the mineral complexes, which is due to the circulation of bases.

The Ca, Mg, and K behave somewhat alike with respect to their distribution in the soil profile. Ca shows a lower accumulation than Mg or K.

The distribution of organic matter in the profile is obscured with respect to the A horizon because of the presence of charcoal due to forest fires. The C:N ratio is not 10, the commonly accepted figure. It is a good deal higher. It is low in A_2, increases in B, and drops in C.

There is a high N content in the organic matter of A_2. It is pointed out that the type of organic matter varies in composition in the different horizons. It is suggested that the crenic and apocrenic acids in A_2 and the prevalence of fungi in A_2 might account for the high N content in the organic matter. There is also an accumulation of organic matter in the B horizon.

The podzol nature of these profiles is very lucidly illustrated by the base exchange capacity and unsaturation in the various horizons.

The colloids from profile 2 have been extracted by the Bureau of Soils method. One of the most important features of the analyses of the colloid fraction is the $SiO_2:R_2O_3$ ratio, which approaches the figure 2 in the B horizon. In general, however, the analyses of the colloids supplement the data on the total analyses.

The soils investigated are mature podzols and both profiles are identical, except that profile 2 is shallower because of the geologic deposits of clay under-

lying the sandy parent material. This caused what was termed a "stunting effect" on the growth of the soil body.

REFERENCES

(1) EDINGTON, S., AND ADAMS, J. R. 1925 Distribution of N in the podzol profile. *Soil Sci.* 20: 177–179.

(2) JOFFE, J. S. 1931 Soil profile studies: III. The process of podzolization. *Soil Sci.* 32: 303–323.

(3) JOFFE, J. S. 1932 Soil profile studies: IV. Morphological and chemical evidence of podzolization. *Soil Sci.* 33: 217–237.

(4) JOFFE, J. S. 1932 Experiments on the movement of iron and aluminum in the soil. *Proc. and Papers Second Internat. Soil. Sci. Cong.* (1930). In press.

(5) JOFFE, J. S. 1932 Lysimeter studies: II. The movement and translocation of soil constituents in the soil profile. *Soil Sci.* 35: 239–257.

(6) JOFFE, J. S., AND MCLEAN, H. C. 1928 Colloidal behavior of soils and soil fertility: IV. Anion effect on the precipitation reactions and degree of dispersion of Fe and Al hydroxides. *Soil Sci.* 26: 47–59; V. The distribution of soluble and colloidal iron and aluminum in soils. *Soil Sci.* 26: 317–325.

(7) LEE, L. L., AND TINE, J. E. 1932 Soil survey of the Freehold Area, New Jersey. Bur. Chem. and Soils, U. S. Dept. Agr. Series 1927, Number 33.

(8) LUNT, HERBERT A. 1931 The carbon-organic matter factor in forest soil humus. *Soil Sci.* 32: 27–36.

(9) MCGEORGE, W. T. 1930 The base exchange property of organic matter. Univ. Ariz. Agr. Exp. Sta. Tech. Bul. 30.

(10) MCGEORGE, W. T. 1931 The base exchange properties of soil organic matter. *Jour. Amer. Soc. Agron.* 23: 331–336.

(11) MATTSON, SANTE 1932 The laws of soil colloidal behavior: VII. Proteins and proteinated complexes. *Soil Sci.* 33: 41–72.

(12) WILLIAMS, V. P. 1927 Obschee zemledelie s osnovami pochvovedeniya. (General agronomy and the fundamentals of soil science.) Moscow.

PLATE 1

THE CONSTITUTION OF PROFILE 2

PLATE 1

SIXTEENTH SESSION OF THE INTERNATIONAL GEOLOGICAL CONGRESS

The third circular for the sixteenth session of the International Geological Congress, which is to meet in Washington, U. S. A., from July 22 to 29, has been issued. It contains full information about meetings and about excursions, with costs. Before the Congress there are excursions to various parts of the eastern United States, lasting from 4 to 12 days, and a transcontinental excursion eastward from San Francisco for those coming to the Congress from the west. For those arriving at New York too late to take part in these longer excursions there will be a number of short trips to nearby areas of geologic interest.

Alternate days during the sessions of the Congress will be given to excursions to areas around Washington.

After the sessions there will be two longer transcontinental excursions, each lasting 31 days, and two shorter excursions, one for the study of the glacial geology of the Central States, the other for the study of the pre-Cambrian area, including the iron and copper deposits, of the Lake Superior region.

In order to make these excursions generally available, it has been possible, through the generous assistance of the Geological Society of America, to offer the longer excursions at a considerable reduction below actual cost.

For special discussion at the scientific sessions in Washington the following topics are announced:

Measurement of geologic time by any method.
Batholiths and related intrusives.
Zonal relations of metalliferous deposits.
Major divisions of the Paleozoic era.
Geomorphogenic processes in arid regions and their resulting forms and products.
Fossil man and contemporary faunas.
Orogenesis.
Geology of petroleum.
Copper resources of the world.

Membership in the Congress is open to any one interested.

For a copy of the third circular or other information address W. C. Mendenhall, General Secretary, U. S. Geological Survey, Washington, D. C.